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摘　要

气候变化以及森林的减少是人类社会面临的严峻问题。气候的变化可能是由人类活动释放二氧化碳到大气中所造成。目前在世界各地已经建立了大面积的人工林以改善环境并提供环境服务，其中包括碳固存、恢复土壤肥力和生物多样性。不同经营模式由于树种、树龄以及经营措施不同，其碳储量大小和分布存在较大差异。本研究以银杏纯林（G）、杨树纯林（P）、水杉纯林（R）、银杏+水杉（GR）和杨树+水杉（PR）五种经营系统为对象，评价不同经营系统土壤性质和碳储量。测量了不同经营系统植被生物量，土壤理化性质和碳储量，结果表明，土壤最大持水量、田间持水量、含水量、土壤有机质、土壤碳储量、易氧化碳、、水溶性碳、微生物量碳、全氮、全磷、硝态氮、铵态氮含量均随土层的增加而降低，而土壤容重和 pH 值随土层的增加而升高。不同经营系统土壤理化性质存在较大差异。不同经营系统林木碳储量表现为 P (57.42 t/ha) > PR (48.33 t/ha) > G (38.34 t/ha) >GR (28.17 t/ha) > R (15.64 t/ha)，林下植被碳储量表现为 P (22.61 t/ha) > GR (2.60 t/ha) > G (2.51 t/ha) > R (1.87 t/ha) > PR (1.76 t/ha)，土壤有机碳含量表现为 P (3.88%) > PR (3.60%) > G (3.17%) > GR (3.14%) > R (2.78%)，土壤碳储量表现为 PR (82.54 t/ha) > P (79.92 t/ha) > GR (67.04 t/ha) > G (63.00 t/ha) > R (57.63 t/ha)。研究结果表明，杨树纯林模式是提高系统碳储量的最佳方式，当我们评价土壤特性和碳储量时，我们不仅要考虑种植类型，还要考虑树木种类、年龄和物种密度。

关键词：碳储量和分布；林木碳储量；林下植被碳储量；土壤有机碳；土壤理化性质

Abstract

Climate change and forest decline is a major problem being faced by human society. Climate change may be caused by human activities that release carbon dioxide into the atmosphere. All over the world, a large area of forest plantations has been established to compensate these conditions and to provide environmental services, including carbon (C) sequestration, restoration of soil fertility and biodiversity. The carbon storage and distribution under different plantations are not the same, especially depending on the treatments, species, age. The objective of this study was to assess the soil properties and carbon storage under the pure plantations of *Ginkgo biloba* (G), *Populus tremula* (P) and *Metasequoia glyptostroboides* (R) and mixed plantations of *Ginkgo biloba* and *Metasequoia glyptostroboides* (GR), *Populus tremula* and *Metasequoia glyptostroboides* (PR). The biomass of tree and understory vegetation, the physical and chemical properties of soil, and carbon storage in different plantations were measured. The results showed that soil maximum and available water holding capacity, water content, organic matter, SOC content, soil carbon storage, ASOC, WSOC, MBOC, total N and P, available N, NO_3^- and NH_4^+ decreased with soil depths, while soil bulk density and pH increased with soil depths. The physical and chemical properties of soil had significant variation in different plantations. The tree biomass carbon storage was P (57.42 t/ha) > PR (48.33 t/ha) > G (38.34 t/ha) >GR (28.17 t/ha) > R (15.64 t/ha), the understory vegetation carbon storage was P (22.61 t/ha) > GR (2.60 t/ha) > G (2.51 t/ha) > R (1.87 t/ha) > PR (1.76 t/ha), the soil organic carbon concentration was P (3.88%) > PR (3.60%) > G (3.17%) > GR (3.14%) > R (2.78%) and total soil carbon storage was PR (82.54 t/ha) > P (79.92 t/ha) > GR (67.04 t/ha) > G (63.00 t/ha) > R (57.63 t/ha). The results suggest that the pure plantation of the poplar was the best for carbon storage among these treatments. When we assess the soil properties and carbon storage, we need to put not only plantation types but also the tree species, stand age and species density.

Keywords: Carbon storage and distribution; Biomass carbon; Understory vegetation carbon; Soil organic carbon; Soil physical and chemical properties.

ABBREVIATION

ANOVA	Analysis of variance
FAO	Food and Agricultural Organization of the United Nations
G plantation	Pure plantation of gingko
GR plantation	Gingko mixed with dawn redwood plantation
P plantation	Pure plantation of poplar
PR plantation	Poplar mixed with dawn redwood plantation
R plantation	Pure plantation of dawn redwood
DBH	Diameter at breast height (1.3 m)
H	Tree height
C	Carbon
SOC	Soil organic carbon
SAOC	Soil active organic carbon
WSOC	Water soluble organic carbon
MBOC	Microbial organic carbon
Available N	Available nitrogen
NO_3^-	Nitrate Nitrogen
NH_4^+	Ammonium Nitrogen
cm	centimeter
m	meter
m^2	square meter
yr	year
gcm^{-3}	gram per centimeter
g/Kg	gram per kilogram
mg/g	miligram per gram
mg/Kg	miligram per kilogram
t/ha	ton per hector

Table of Contents

List of figures

List of tables

1. Introduction

The increasing of greenhouse gases (GHG) in the atmosphere will result in major effects on the current situation. It is essential that a number of actions to be undertaken in order to reduce GHG emissions and to increase their sequestration in soils and biomass. In an ecosystem, photosynthesis leads to carbon 'gained', and respiration of all components results carbon 'lost' or 'released', and the difference value represents net ecosystem productivity. Most of the carbon enters into ecosystem via photosynthesis of plant leaves, then the carbon accumulates in plant biomass. More than half of the assimilated carbon is eventually transported below ground via root growth and turnover, root exudates (of organic substances), and litter deposition, and therefore soils contain the major stock of C in the ecosystem. Forests and forest soils play an important role in climate change as a sink or source of carbon pool and carbon sequestration. The carbon storage and sequestration potential of natural forest and plantations can be assessed by estimating above- and below-ground carbon.

Total forest areas were declined by 3% (from 4128 M ha to 3999 M ha) between 1990 and 2015. The net rate of annual lost was from 7.3 M ha y^{-1} in the 1990s to 3.3 M ha y^{-1} between 2010 and 2015. Especially, the forest area had a quick rate of decent from 1966 M ha in 1990 to 1770 M ha in 2015 in the tropics and from 618 M ha in 1990 to 684 M ha in 2015 in the temperate (Keenan et al. 2015). So the plantations are established to compensate the forest lost in all over the world. China is one of the countries with the largest artificial forest areas in the world (Winjum and Schroeder, 1997) and has 24% of the global forest plantations (Carle et al. 2002). The total plantation area reached 6.2×10^7 ha, accounting for 31.8% of the total forest area of China (Department of Forest Resources Management, SFA, 2010). Tree plantations of China in recent years have a rapid growth (FAO, 2010), and forest area expanded by 1.5M ha y^{-1} between 2010 and 2015 (Keenan et al. 2015). The weather conditions in subtropical China, such as abundant precipitation, mild winters and long growing season, make it possible to get the higher forest productivity (Chen et al. 2011).

The carbon status and stock in forest ecosystem were affected by many factors. The forest C stock of different latitudes differs widely, and C stock occupies 37% in low latitude forests, 14% in mid-latitudes and 49% in high-latitudes. The above-ground plant C density increases with the decreasing of latitude from tundra to the tropical rainforest (Fisher, 1995). Budge et al. (2011)

noted that annual C-exchange of the soil-atmosphere is estimated around 80–98 Pg (Raich et al. 2002; Bond-Lamberty and Thomson, 2010), and it has a strong influence on global warming (Friedlingstein et al. 2006; Jones et al. 2005). As a result, vegetation (primary production) is CO_2 assimilation and ecosystem respiration is CO_2 release. In the current, conversion of soil organic carbon (SOC) that may cause unexpected patterns of climate change and serves as a pool of atmospheric C (Davidson et al. 2006).

Plantation types, tree species and stand age also affected carbon storage and sequestration of forest plantation (Wei et al. 2013; Chen et al. 2015). In addition, plantations not only reduce the pressure on natural forest, which are the largest sink of terrestrial C but also have an indirect effect on C sequestration. Comparing with other land-use, the plantation is believed to have a higher potential to sequester carbon (C) because of their perceived ability for greater capture and utilization of growth resources (light, nutrients and water). The significant soil C sequestration can occur in old reforested and afforested ecosystems in the tropic (Silver et al. 2004). Total C storage in temperate was greater than in boreal forests, and also in older stands was greater than in younger stands (Wei et al. 2013). When long-lived woody plants die and decompose, the carbon in wood and other tissues may be released to the atmosphere in the manner of carbon dioxide, carbon monoxide, or methane, or it may be incorporated into the soil as organic matter (Anderson et al. 1991). By transforming from mono-specific to mixed species plantations, carbon sequestration can be increased in the subtropical forest ecosystem (Wang et al. 2013). In mixed species plantations, the competition of intra-specific may be more than the inter-specific for tree growth (Petit et al. 2006). Some growth variables in the mixed plantations are better than the pure plantations usually, such as height, diameter at breast height, volume and aboveground biomass (Piotto et al. 2010). In mixed-species plantations, more carbon sequestration, higher biodiversity and better soil quality were also found (Richard et al. 2007).

In previous intensive studies concerning the effect of aboveground and belowground carbon content and sequestration between the pure plantations and mixed plantations (Forrester et al. 2006, Lee et al. 2009, Forrester et al. 2013), but very few have focused on soil physical, chemical and ecological properties. Information on the changes of these properties is required for a better understanding of the plantation treatments and the interaction between soil and plant community and for the appropriate management and implementation of the environmental conservation. The objective of this study was to find out the variation of carbon storage and soil properties in different plantation ecosystems.

1.1. Principle of the study

Forests are a significant part of the global carbon cycle. Plants use sunlight to convert CO_2, water, and nutrients into sugars and carbohydrates, which accumulate in leaves, twigs, stems, and roots. Plants also release CO_2 through respiration of organs. Plants eventually die, and release their stored carbon into the atmosphere quickly or to the soil where it decomposes slowly and increases soil carbon levels. However, little information exists on the processes and diverse rates of soil carbon change. Rouhi (2008) pointed that plants could influence soil properties due to differences in litter quality, root activity, canopy interception of atmospheric deposition, nutrient uptake, and growth (Alban, 1982; Miles, 1985; Binkley, 1995; Hagen-Thorn et al. 2004).

In a forest ecosystem, carbon sequester (CS) occurs in two major segments: one is an aboveground part, such as stem and leaf of a tree, and another is an underground part, such as roots of the plant, soil organisms and soil animals. Both of sequestered carbon number depends on many factors, such as the region, the type of system, site quality, and previous land-use. Nair (2010) noted that soil carbon has been estimated about 60% of total C, and aboveground has only 30% in tree-based land-use systems (Lal, 2005; 2008). Thus, sequestering carbon (C) in soils are important due to increasing of greenhouse gas emissions and global warming, and soils are critical of the global C pools in different ecosystems (Banger et al. 2010).

Soil improvement under trees and plantation systems is related to increases in organic matter greatly, whether in the form of surface litter or soil carbon. Therefore, besides their role in above- and below-ground carbon sequestration, plantation systems have a great potential to increase carbon stocks in the soil. So, the plantation is important for carbon sequestration. And also certainly merit consideration in mechanisms that propose payments for mitigation of greenhouse gas emissions to reduce climate change.

Soil bulk density can be managed in plantations, using measures that limit compaction and build soil organic matter. When bulk density is determined, the soil moisture content must be determined. The soil water resource is an important factor, but it is difficult for plant ecologists to use because of the lack of accessible data. The maximum and available amount of water were important soil parameters to provide water for plant growth. It is estimated by the soil maximum water-holding capacity, which is defined as the amount of water held between field capacity and wilting point (specified in cm of water for a soil of a given depth) (Bruand et al. 2003). Plant available water is that portion of the water holding capacity that can be absorbed by a plant. The soil water regime affected plant growth, carbon allocation, microbial activity, nutrient cycling and the rate of photosynthesis (Lebourgeois et al. 2005; Breda et al. 2006).

1.2. Objectives of the study

The main objective of this study is to assess the soil properties and carbon storage under different forest plantations. The specific objectives are

i. To evaluate the carbon storage of different managing ecosystems,

ii. To examine the distribution of carbon under different managing ecosystems,

iii. To assess the soil physical and chemical properties of different managing system.

1.3. Conceptual framework

The following conceptual framework was followed to reach my studied objectives;

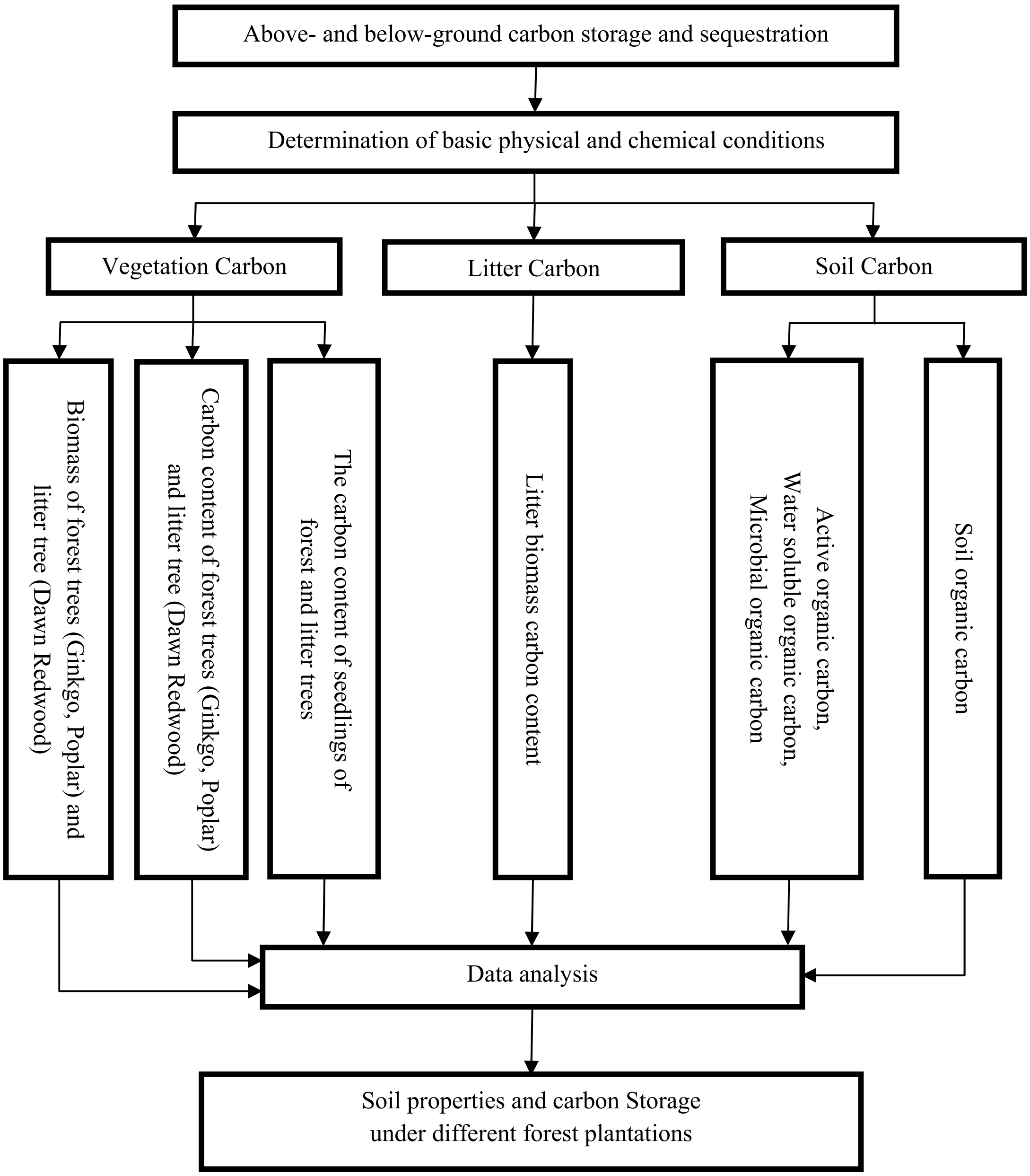


Figure1. Conceptual framework of the study

2. Literature review

2.1. Bioecological characteristics and utilizations of gingko (*Ginkgo biloba L.*)

Ginkgo (*Ginkgo biloba L.*) is a deciduous gymnosperm and native species in China. It is the only remaining species of the large order Ginkgoales. According to geological records it presence on earth for 150–200 million years (Xingyuan et al. 2009). The name ginkgo is derived from the Chinese YIN, silver, and HING, apricot (Whetstone, 1993). It's also known as Ginkgo, maidenhair tree, yin hing 银杏 yin xing. Ginkgo biloba belongs to single plant division - Ginkgopsida, subdivision - Coniferophytina, classes - Pinopsida and Ginkgoopsida, order - Ginkgoales, family - Ginkgoaceae, genus - Ginkgo, and species - *G. biloba* (Melzheimer, 2000).

Ginkgo biloba L. (Ginkgoaceae) is an ancient tree growing in China for centuries, however, its health-promoting properties were only considered during the last couple of decades (Smith et al. 1996; Singh et al. 2008). The oldest living ginkgo tree species has flourished in forests for over 150 million years and hence it is called a "living fossil" (McKenna et al. 2001). It is a dioecious tree with the male and female reproductive organs on separate trees. They have a large trunk with a girth of about 7m and height of about 30 m. A young tree is a conifer like and exhibit branching dimorphism. The tree is deciduous reaching a height of 4 m, with a reddish bark. Leaves that grow in clusters are golden yellow in fall during senescence. The leathery leaves are very uniquely shaped with 2 lobes and resemble the maidenhair fern in shape and venation. The pollination process involves the male microstrobili bearing loosely distributed sporangiophores containing microspores with male gametophytes and the female pendulous pairs of ovules borne on the shoots. These trees begin to reproduce after about 20 years by developing naked seeds (nuts) with an outer fleshy layer (fruits). The outer fleshy layer of the fruit has a considerable amount of butanoic and hexanoic acids, which are responsible for the rotting flesh, fermented odour (McKenna et al. 2001).

Ginkgo (*Ginkgo biloba L.*) is a traditional economic tree species in China, except Sinkiang, Inner Mongolia, Tibet and Hainan. It is cultivated widely in some regions of China to harvest its leaves, flowers, fruits and timber. Due to Ginkgo is slow-growing species, the practice of Ginkgo agroforestry has been adopted in order to obtain more economic benefits during the process of establishment. Researchers and farmers in Jiangsu Province are intercropping Ginkgo with many forest and crop species and forming different forest ecosystems. Each has different ecological and economical benefits (Wang and Cao, 2011). Ginkgo leaves, which have medical properties and various common geriatric complaints, have been cultivated for several thousand years (Ward et al. 2002).

Although the plants are highly resistant to pathogenic infections, especially of bacteria and fungi, their wood is not of much commercial importance. It also possesses a strong capacity of resistance to air pollution by smoke and poisonous gases. Since an unpleasant odour is emitted from the ripe seeds of female trees, male trees are largely preferred and grown as shade trees in China, Japan and the United States. Ginkgo trees grow and develop very slowly. Ginkgo trees are easy to grow, tolerating a wide range of soils, including clay and sand. However, they prefer well-draining soil and are very drought tolerant. Ginkgo trees do well in full or partial sun, as well as partial shade. The roots of the tree are not problematic for pipes, foundations or sidewalks, and it is generally free of pests and other diseases. These inferred habitats are surprising because the life-history traits of Ginkgo (e.g., slow growth rate, late reproductive maturity, extended reproductive cycle, large and complex seeds, large and slowly developing embryos) are counter to those considered advantageous in modern disturbed habitats.

However, most studies on Ginkgo were focused on extract activities, whereas less attention was paid to its silvics. It is of biological and commercial importance to understand the environmental factors affecting flavonoids biosynthesis as this knowledge is essential to the development and production of high-flavonoid yielding plantations. Several studies have been conducted to investigate the effects of light, temperature, and drought on flavonol content in Ginkgo leaves and genomic studies have been conducted to understand their biosynthesis through the cloning and study of several flavonoid biosynthesis genes (Xu et al. 2014). Additionally, we need to analyse how much carbon can be stored and sequestered in the Ginkgo plantations.

2.2. Bioecological characteristics and utilizations of poplar (*Populus tremula*)

Poplars (*Populus*); a very old genus, are popular park trees and ornamentals. Fossils have been discovered in earth layers formed in the Cretaceous but unclear between different poplar species.

It has various names, Cottonwood, Common Aspen, Eurasian Aspen, European Aspen and *Populus tremula* L. in Latin. It belongs to the family **-** Salicaceae and genus - *Populus* (Kole, 2007). This species is native to cool temperate and boreal regions of Europe and Asia and the second most widely distributed tree in the world, after Scots pine (*Pinus sylvestris*) (MacKeznie, 2010).

Eurasian aspen (*Populus tremula* L.) is a medium-sized, fast-growing tree, exceptionally reaching a height of 30 m. The trunk is long and slender, rarely up to 1 m in diameter. The light branches are rather perpendicular and the crown has a conicpyramidal shape. The leaves are 5-7 cm long, simple, round-ovate, with big wave-shaped teeth. The Eurasian aspen (*Populus tremula L.*) is a fast-growing broadleaf tree and can tolerate a wide range of habitat conditions (Kole, 2007). Its fast-growing habit continues until the age of about 20 years and its growth increment is slower and culminates at about 30 years of age. The average lifespan is 50-100 years and rarely exceeds 100 years of age (MacKenzie, 2010; Caudullo & de Rigo, 2016).

It reaches considerable girth only on rich soils in broadleaf or mixed woods. In spring the young leaves are coppery-brown and turn to golden yellow in autumn, making it attractive in all vegetative seasons. The aspen is a dioecious tree. Flowers are produced in February-March before the leaves appear. It can grow on a wide range of soils, from slightly dry to wet soils of poor to rich nutrient status. Light is also more important than soil conditions. The wood is not dense, but it is mainly used for veneer and pulp for paper production, also for good quality charcoal and chip-wood. It is used as a biomass crop for energy production because of its rapid growth. As a pioneer species, Eurasian aspen is often used for afforestation of barren or degraded lands and planted as a windbreak **(**Caudullo & de Rigo, 2016).

Several of these features made poplars attractive to humans since ancient times. Today, poplar is cultivated worldwide in plantations for pulp and paper, veneer, excelsior (packing material), engineered wood products (e.g., oriented-strand-board), lumber, and energy. In a commercial plantation, it was grown under intensive culture with 6- to 8-year rotations. The production rates of hybrid poplar can be as high as 17 to 30Mg/ha/year of dry woody biomass, comparable to the biomass produced by row crops such as corn. Historically, poplar has been widely used in windbreaks and for erosion control (Isebrands & Karnosky, 2001). Aspen is an important factor in maintaining the biodiversity of forest ecosystems as it provides a home for many species of animals, fungi, and plants. Wood is whitish, soft, and decay-resistant which makes it a suitable raw material in construction and for various implements. Traditionally, aspen wood has been used for making matches, plywood, and sauna benches.

Poplars that make excellent for short-rotation intensive culture management: rapid juvenile growth, immediate response to cultural practices, and their coppicing property (Bradshaw et al. 2000). *Populus* has several advantages as a model system, including rapid growth, prolific sexual reproduction, ease of cloning, small genome, facile transgenesis, and tight coupling between physiological traits and biomass productivity. A combination of genetics and physiology is being used to understand the detailed mechanisms of forest tree growth and development (Kole, 2007). Poplars were widely used in China for plantations establishment and need to be assessed the amount of carbon that can store in their ecosystems.

2.3. Bioecological characteristics and utilizations of dawn redwood (*Metasequoia glyptostroboides Hu et Cheng*)

Dawn Redwood (*Metasequoia glyptostroboides Hu et Cheng*) is a beautiful and fascinating tree. Earlier in the 20th century, *Metasequoia* was thought to be extinct and was only known to botanists from fossil records. It was also known initially from fossil material. In the 1940s the species was identified in China. It has various names; Dawn Redwood in English, Shui-sha-ba (water-fir) in Chinese, "Living Fossil" in general favour, *Metasequoia glyptostroboides* in Latin, the scientific name, and family**:** Taxodiaceae and the single species genus: *Metasequoia* that has been found almost sixty years from central China (1941-2000). The plant has been cultivated almost all over the world and has been apprised widely both from the professionals and amateurs. Its present natural range is limited to small, highly disturbed areas of western Hubei, northern Hunan and eastern Sichuan provinces in central China (Chu & Cooper, 1950; Bartholomew et al. 1983; Fu & Chin, 1992).

The Dawn Redwood is a monoecious plant with the male (microsporangiate strobili) and female cones (macrosporangiate strobili) being borne separately on different branches of the same tree. Before they produce male pollen cones, trees are able to produce female cones many years (Wyman, 1968; Kuser, 1983). Several reports suggest that viable seed is not produced until the trees reach 25 to 30 years old.

The Dawn Redwood is a rare deciduous taxodioid conifer with a highly restricted natural distribution in central China. It is a riparian species that is restricted to wet lower slopes and montane river and stream valleys in its native range (Chu & Cooper, 1950). Whereas the variability of climate across its natural range is a minute, under cultivation it grows across a gradient of 16.3 ˚ C of mean annual temperature and 2360 mm of mean annual precipitation but can't grow less than 500 mm of mean annual precipitation (Williams, 2005). It is a species that has undergone considerable range contraction. Despite the relatively narrow range of climate found in its natural range, it is tolerant of a wide range of climate conditions when cultivated. Its growth beyond its natural range appears to be limited by low growing season water availability and extremely cold temperatures.

The Dawn Redwood is a fast grower (over 2' feet per year) with a narrower crown form than the straight species. It is a large tree that needs room to grow. It grows in a perfect pyramid 70 to 90 feet tall and was known from fossils before living plants were discovered in China. Although it looks like an evergreen, the needles are deciduous. It is a fast growing plant that attains diameters in excess of 2 m and tree heights up to 51 m in its natural range. Under ideal conditions during cultivation, it can attain impressive heights in relatively short time periods. Williams et al. (2003) pointed that based on measurements of its growing in plantations; it appears that most of the height growth occurs early in stand development with vertical extension slowing through time. For example, average annual height increments of 86 to 103 cm yr^{-1} have been reported for 17 to 20-year-old trees in Japan (Satoo, 1974; Ikeda, 1980). These same trees measured at 48 years had reduced their vertical growth to between 48 and 56 cm yr^{-1} (Williams *et al.*, 2003).

In its native range, large *M. glyptostroboides* occur as a canopy emergent species rising above the surrounding vegetation. This is consistent with its growth characteristics such as rapid shoot elongation, rapid juvenile growth and indeterminate growth (Jagels & Day, 2004). In monospecific stands of *M. glyptostroboides*, canopy closure occurs rapidly, usually in 10 to 14 years depending on stem density (Williams *et al*., 2003). As a result, light levels can be extremely low under intact *M. glyptostroboides* canopies (Vann *et al*., 2003). As a fast-growing species, Dawn Redwood plays an important role in carbon stocks and other ecosystem services. It might be of interest as a source of plantation grown softwood (Polman et al. 1999). Dawn redwood was widely planted due to its fascinating. We need to analyses the environmental benefits of the dawn redwood plantations.

2.4. Carbon sequestration in forest

Global climate change is widespread and growing in all over the world. Therefore, scientists have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans. Among them, to reduce the rise of greenhouse gas concentrations in the atmosphere and to increase the amount of carbon removed by and stored in forests are critical for climate change. Globally, over half of all terrestrial carbon exists in forests; which play for carbon exchange between terrestrial ecosystems and the atmosphere up to 80%. Annually the estimated amounts of 3 Pg (3 billion tons) of carbon are absorbed by forest ecosystems (Montagnini et al. 2004). Forests play a significant role in this carbon (C) sink. It has been reported that forests store about 45% of terrestrial C, more than double the amount of C in the atmosphere (FAO, 2006).

2.5. Carbon cycling in forest

Carbon is held in the terrestrial system in vegetation and soil. Plants use sunlight to convert nutrients into sugars and carbohydrates within photosynthesis process. Carbon dioxide (CO_2) is one of the nutrients essential to building the organic chemicals that comprise leaves, roots, and stems. So all parts of a plant contain carbon but not the same proportion in each part depends on the plant species, age and growth pattern. Nonetheless, as more photosynthesis occurs, more CO_2 is converted into biomass that reduces carbon in the atmosphere and sequestering it in plant tissue above- and below-ground. When the plant dies, carbon is released to the atmosphere but for woody plants, some of the above-ground biomass continues to store carbon until the plant dies and decomposes. Thus, the amount of carbon sequestered in a forest is constantly changing with growth, death, and decomposition of vegetation. In forest ecosystem, tree biomass is also an important characteristic that affects the accumulation of organic carbon and ecosystem productivity (Dixon et al. 1994, Clark et al. 2001, Masera et al. 2003, Grace 2004, Lal 2005) and can manage for monitoring the development of restored ecosystems (Naeem et al. 2009). By establishing tree plantations on cleared land in the tropics, that can reduce the rate of increase in atmospheric CO_2 (Dyson, 1977). As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases (within a forest or in forest products), the increase in atmospheric CO_2 is mitigated.

In addition, carbon is also sequestered in forest soils. Carbon is the organic content of the soil. The amount of carbon in soils varies widely, depending on the environment and the history of the site. Soil carbon accumulates as the dead plant is added to the surface and decomposers respond and is injected by roots grow. Soil carbon is slowly released to the atmosphere as the plant decomposes. And also in global C cycle, the soil is a source of C pool contains estimated amount of 1550 Pg (1 pentagram = 10^{15} g = 1 billion tones) of soil organic C (SOC) and about 750 Pg of soil inorganic C, both found in 1-m depth (Batjes, 1996). Thus, soil carbon (SC) is three times the atmospheric pool of 770 Pg and 3.8 times the vegetation pool of 610 Pg; a reduction in soil C pool by 1 Pg is equivalent to an atmospheric enrichment of CO_2 by 0.47 ppmv (Lal, 2001).

2.6. Role of biomass in forest ecosystem

Forest litters, forest or crop residues, cover crops or vegetations are important parts of the ecosystem that serve as carbon storage. If the density of the forest biomass increases, the forest carbon will also increase. By increasing carbon input to the soil from plant residues, there will be an increase in C sequestration by the aboveground biomass. Depending on the tree species, the amount of biomass in plantation systems returned to the soil varies and soil C stocks under poly-cultures accrue more than a monoculture of trees (Nair et al. 2009; Russell et al. 2004). Fast-growing species accumulate biomass and carbon very fast in the first stage of their previous lifespan but slower-growing species may accumulate more biomass and carbon within the system in the long term, compared to stands or mixtures of fast-growing species only (Redondo-Brenes & Montagnini, 2006; Montagnini, 2000). Mean annual litter fall and biomass of mixed-stand was significantly higher than that of mono-stand, so the soil availability nutrient in the mixed stand was richer than that of mono-stand (Wang et al. 2008; Montagnini et al. 1995) and mixed species plantation increased C sequestration (Wang et al. 2013; Wang et al. 2009). For an example of plantations management, mixed species plantations of white spruce and hybrid poplar promoted carbon sequestration (Chomel et al. 2014).

Upson et al. (2013) noted that as the result of trees into plantations, the carbon stored by aboveground biomass accumulation is liable (Janzen 2005), but it depends on the woody biomass. On the other hand, carbon accumulated in the soil can persist for millennia (Rumpel et al. 2002, Schoning and Kogel- Knabner 2006) and forms the largest terrestrial carbon pool (Batjes 1996). Therefore, the destructive method will be used in this study by developing allometric equations through above- and below-ground carbon storage and sequestration under different treatments for analysis using biomass, DBH, height, root and soil collection.

2.7. Role of soils in forest ecosystem

Soil organic carbon (SOC) represents the largest reservoir in the terrestrial carbon cycle that interaction with the atmosphere and is estimated at about 1500 Pg C to 1m depth (about 2 456 Pg C to 2m depth). And inorganic C represents around 1700 Pg. Vegetation (650 Pg) and the atmosphere (750 Pg) store considerably less C than soils do (Robert 2001). Fluxes between terrestrial and the atmosphere are important and can be positive (sequestration) or negative (emission of CO_2). Due to changing in land use; deforestation and increase in pasture and cultivated lands, the emission were around 140 Pg from 1850 to 1990 (from 0.4 Pg yr^{-1} in 1850 to 1.7 Pg yr^{-1} in 1990), with a net release to the atmosphere of 25 Pg C (Houghton 1995). The rate of SOM mineralisation depends mainly on temperature and oxygen availability (drainage), land use, cropping system, and soil and crop management. Forest ecosystems contain more carbon per unit area than any other land use type, and their soils – which contain around 40 percent of the total carbon - are of major importance when considering forest management (Robert 2001). Paul et al. (2002) noted that the world's soils hold about 75% of total terrestrial C (Henderson, 1995), and about 40% of all belowground C is stored in forest soils (Dixon et al. 1994; Huntington, 1995). Montagnini et al. (2004) reported that soil carbon (SC) is 1.5 to 3 times more than found in vegetation (Dixon, 1995) and also among world soil carbon, 13% are found in tropical topsoil (Young, 1997).

Forest soils C content causes the variation of climatic and soil properties, for example, the forest soils C content in cooler climates is twice of the warm temperate forest soil (Degryze et al. 2004; Post et al. 1982). Carbon storage of all forests is not equal. Generally, longer lived trees with high-density wood can store more carbon per volume than short-lived, low density, fast-growing trees. This does not mean that carbon offsets which involve big, slow-growing trees are necessarily better than those involving plantations of fast-growing trees (Moura 1996). The content of SOC in plantations is higher than agricultural crop or bare-land due to incorporation of tree biomass (i.e., leaves, branches and twigs), that add organic matter to the soil and improve its quality, and penetration of tree roots, that bring nutrients to the surface via leaf fall (Tumwebaze et al. 2012; Schroeder 1993). Jose et al. (2012) found that the amount of C sequestered in a monoculture field of crop plants or pasture can increase by incorporating of trees or shrubs on farms or pastures (Sharrow and Ismail 2004; Kirby and Potvin, 2007). Chander et al. (1998) noted that the productivity of crop is influenced by shading trees than the other factors (Palm, 1995; Puri and Bangarwa, 1991) and removing above-ground portions with no incorporation of the residues in the soil except root biomass. Carbon (C) exists in the dry weight of branches is almost 50% and foliage is 30% but below-ground C sequestration is high, around 2/3, due to living biomass and C stored in various soil horizons (Pinho et al. 2012; Nair et al. 2010).

The SOC concentration and pools will be increased in soils as the age of tree increases. Although the SOC concentration and pools in the loamy sand are higher than in sandy clay, especially the variation in plantations effects on only tree age but not on soil type. For example; the organic carbon sequestration rate of poplar trees during the initial years in sandy clay soils was lower than the subsequent years (Gupta et al. 2009). Soil carbon storage in mixed stands is more than pure stand and carbon concentration in the mineral soil also decrease with depth. On average, 50% of mineral carbon was stored within the upper 20 cm in all the stands (Wang et al. 2013; Fan et al. 2013).

Roots are one part of the soil C balance, because of the large amounts of C is found in that part. Over a third of the plant C is transported below ground via root growth and turnover, root exudates (of organic substances), and litter deposition. Nair et al. (2009) noted that root biomass can be estimated from root-to-shoot ratios. The ratio is the lower range 0.18 of tropical forests to the higher range 0.30 of temperate and boreal forests. Depending on rooting depth, C can store below the plough layer which leads to longer residence times in the soil to avoid disturbance. Therefore, root biomass in plantations is essential that can input C to the soil for substantial in plantations.

3. Materials and methods

3.1. Study area

This study site is situated at Dongtai forest farm of the China East Sea (Yellow Sea),. It is located at the junction of three cities: Nantong, Taizhou and Yancheng (32 ° 33 '- 32 ° 57' N, 120 ° 07' - 120 ° 53'E), and it belongs to the Yangtze River Delta economic development zone along the Yangtze River. The China East Sea (Yellow Sea) is an east part of Pacific Ocean. It has a coastline of 85 km and a wetland of more than 10,000 hectares. It situates on north subtropical moist monsoon climate zone and has the warm and humid condition. The annual average temperature is 15.6 ℃, which varies from the maximum temperature of 35.9 ℃ and a minimum temperature of 7.5 ℃. The annual precipitation is 1044 mm, annual evaporation is 911.9 mm, the annual average frost-free period is 237 days, and annual sunshine duration is 2209 h. It situates on relatively flat terrain, belongs to the middle and lower area of the Yangtze River alluvial plains. The soil is sandy soil and soil organic matter content is 1.4%.

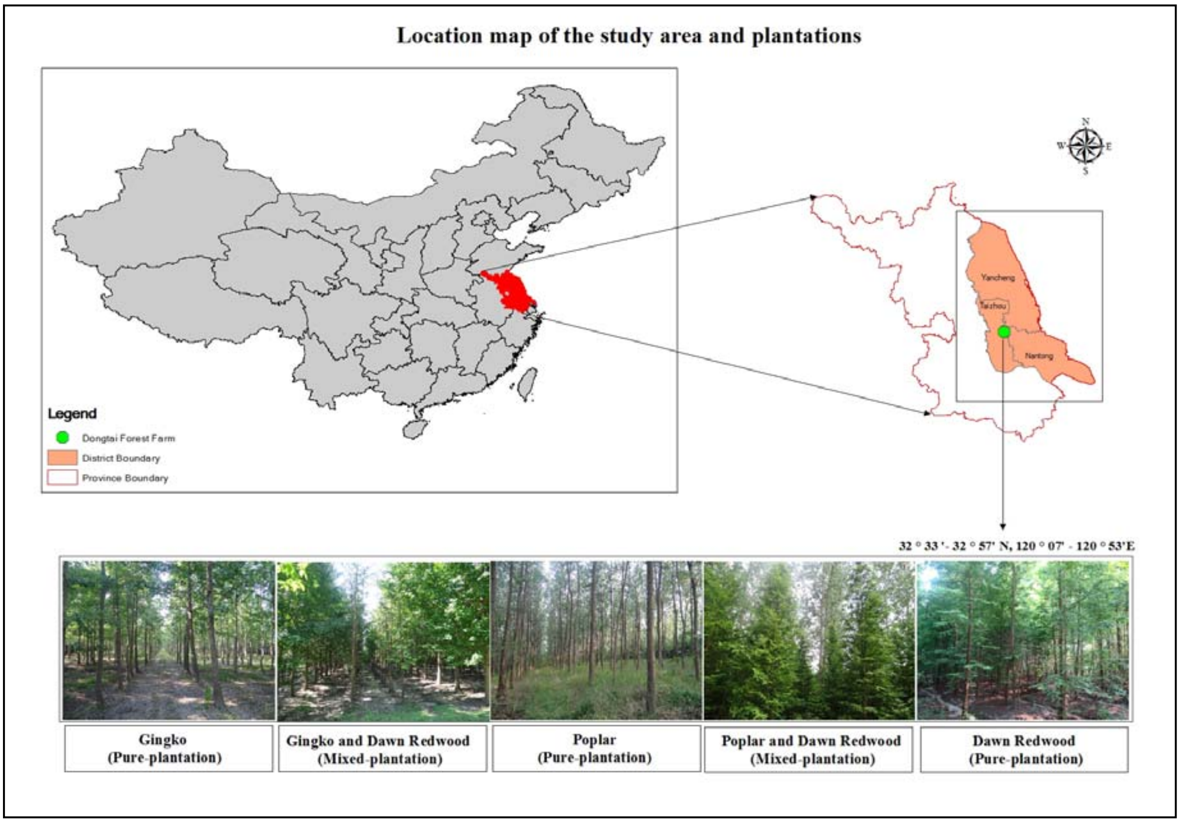


Figure 2. Location map of the study area and plantations

3.2. Studied plantations

The studied plantations situated Dongtai forest farm. The treatments were Ginkgo (*Ginkgo biloba L.*) pure plantation (G), Gingko mixed with Dawn Redwood plantation (GR), Poplar (*Populus tremula*) pure plantation (P), Poplar mixed with Dawn Redwood plantation (PR) and Dawn Redwood (*Metasequoia glyptostroboides*) pure plantation (R). All plots were characterised by similar parent material, soil texture, topography and meteorology. The basic properties of the plantations were presented in Table 1.

Table1. General status of the different plantation treatments

Treatments	Age (yrs)	Spacing (m)	Area (m^2)	Mean DBH (cm)	Mean Height (m)
G	15	3 x 3	500000	15.26±2.47	10.73±1.29
GR - G	15	2 x 8	900000	17.09±2.97	11.23±1.67
R	6	1.8 x 1.8		5.92±2.06	7.17±1.87
P	10	3 x 5	30015	20.85±4.03	18.91±2.99
PR - P	10	4 x 8	30015	27.82±3.52	20.63±2.92
R	6	1.8 x 1.8		5.80±1.95	6.76±1.64
R	6	1 x 1	40020	5.49±1.48	6.62±1.33

3.3. Experiment design

A 10m × 10m sample plot was chosen for every managing plantation with three repetitions, and soil samples were obtained from each plot. Five points on "S" type curve were selected in each plot with three repetitions, and profile of each pit to 1-m depth to determine chemical properties.

3.4. Overstory and understory biomass

Stand density, tree height, and diameter at breast height (DBH, 1.3 m above ground) were measured in each treatment. We used a Gingko growth model (Table 2), Poplar growth model (Table 3) and *Metasequoia glyptostroboides* organs biomass curve regression model (Table 4) developed specifically for southern China to estimate plant biomass (Wang, 2009, Li, 2010), including leaves, branches, stems, and roots, in each treatment.

Table 2. Allometric regression models used to estimate biomass for Gingko

Component	Allometric Equation	R^2
leaf	$\ln W = -6.95 + 1.03\ln(D^2H)$	0.853
branch	$\ln W = -9.38 + 1.46\ln(D^2H)$	0.852
stem	$\ln W = -3.84 + 0.95\ln(D^2H)$	0.980
root	$\ln W = -5.6 + 1.07\ln(D^2H)$	0.970
total	$\ln W = -4.07 + 1.05\ln(D^2H)$	0.972

*D is the stem diameter at breast height, H is the tree height and W is the dry weight of different components.

Table 3. Allometric regression models used to estimate biomass for Poplar

Component	Allometric Equation	R^2
leaf	$W = 0.0351 \times (D^2H)^{0.6821}$	0.878
branch	$W = 0.0430 \times (D^2H)^{0.7183}$	0.879
stem	$W = 0.0373 \times (D^2H)^{0.8629}$	0.994
root	$W = 0.0093 \times (D^2H)^{0.8943}$	0.952
total	$W = 0.1236 \times (D^2H)^{0.8040}$	0.957

*D is the stem diameter at breast height, H is the tree height and W is the dry weight of different components.

Table 4. Allometric regression models used to estimate biomass for Dawn Redwood

Component	Allometric Equation	P
stem	$Y = 1.48836 \times (D^2H)^{0.01384}$	<0.001

*D is the stem diameter at breast height, H is the tree height and Y is the dry weight of different components.

Understory biomass (shrub and herbaceous material) was determined by destructive harvesting. Three 1 × 1-m quadrants in each shrub subplot were randomly selected in which we measured the above- and below-ground biomass of herbaceous material and also all shrub biomass, including leaves, branches, and roots (>2 mm), was harvested in March, July, October and January. All biomass components were dried at 65 °C to constant weight.

3.5. Litter fall biomass

Litter biomass includes dead plant material such as fruit, leaves, bark, and small branches (<2.5 cm) on the soil surface. All litter was collected from the three 1 × 1 - m herbaceous quadrants in each shrub subplot in March, July, October and January and was dried at 65 °C to constant weight.

3.6. Soil sampling

The soil samples were taken with the volumetric cylinder which was made by stainless steel material with 1 mm of thickness and 5 cm in internal diameter and height to determine the soil bulk density. The soil sample was collected in March, July, October and January. Soil samples were taken from 0-10, 10-20, 20-40, 40-60 and 60-100 cm with a cutting ring for each plot. The soil samples were collected with the stainless steel core from another profile, and it was taken the back lab to determine chemical properties after air drying, crushing, sieving, and processing. All samples were sieved with 2 mm screen to discard roots and other debris.

3.7. Laboratory analysis

The biomass samples were oven-dried, ground, and passed through a 1-mm sieve. The amount of C storage in tree components was estimated by multiplying with the C concentration percent of each component.

Soil bulk density was determined with the soil cores sampled by using the volumetric cylinder. That soil body puts in a conventional oven at 85ºC for 48 hrs to get the weight of oven dry soil for calculating physical properties. These soil cores were also used for the determination of the maximum water-holding capacity of the soil. The bottom of soil cores was closed with a fine mesh and then saturated with water for 12 hrs. The soil body sucked off the surplus water and then put on the sand bed. The remaining water in the soil was the maximum water-holding capacity.

Soil pH was measured in a soil-water suspension (2.5:1 soil–water ratio, respectively) with Sartorius PB-10 Basic pH Meters. Some of the air-dried samples were ground and passed through a 0.15mm sieve for the determination of soil organic carbon content and chemical properties. Soil organic carbon content was determined by potassium dichromate oxidation - external heating method, soil microbial carbon was determined by extracting with chloroform fumigation extraction, and some with liqui TOC measurement (Lin, 2010).

3.8. Calculation and statistical analysis

Soil bulk density values from volumetric cylinder were calculated from the mass of a unit volume of dry soil as describes in the calculation formula follow (Lestariningsih & Hairiah, 2013).

$$\text{Bulk Density (g/cm}^3) = Wd/ Vt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, Wd = Weight of oven dry soil (g),

Vt = Volume of apparatus (cm^{-3}).

For water content, soil samples are dried at 105 ± 5 ◦C until mass constancy is reached. The differences in masses before and after drying are a measure for the water content of soils. The water content is calculated on a volumetric basis (cm^3 water/cm^3 soil). Water content (w_{H_2O}) on a dry mass basis expressed as percentages by mass to an accuracy of 0.1% (m/m) using the following equations (Margesin & Schinner, 2005).

$$w_{H_2O} = \frac{m_1 - m_2}{m_2 - m_0} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where;

m_0 = mass of the empty container with lid (g)

m_1 = mass of the container with air-dried soil or field-moist soil (g)

m_2 = mass of the container plus oven-dried soil (g)

Soil organic carbon (SOC) calculated with the following formula (Lin, 2010).

$$\text{Organic carbon (\%)} = \frac{\frac{0.8000 \times 5.0}{V_0} \times (V_0 - V) \times 0.003 \times 1.1}{m_1 \times K_2} \times 100 \quad \ldots\ldots\ldots (3)$$

where;

0.8000 ----------- $1/6K_2Cr_2O_7$; The concentration of standard solution (mol/L)

5.0 ----------- $1/6K_2Cr_2O_7$; The volume of standard solution (ml)

V_0 ----------- Blank calibration with $FeSO_4$ volume (ml)

V ----------- Titration soil sample with $FeSO_4$ volume (ml)

0.003 ----------- The molar mass of carbon atoms (g/mmol)

1.1 ----------- Oxidation correction coefficient

m_1 ----------- Air-dried soil quality (g)

K_2 ----------- Soil conversion to drying soil moisture conversion factor

The total soil carbon stock (C_t, t/ha)of soil organic C to a depth of 100 cm was calculated based on the organic C content, sampled depth, and bulk density with the following formula (Guo & Gifford, 2002).

$$C_t = BD \times C_c/100 \times D \times 100 \quad \text{----------------} \ (5)$$

where;

C_t ----------- total soil carbon stock (t/ha)

BD ----------- the soil bulk density (g/cm^3),

C_c ----------- the SOC concentration (%),

D ----------- the soil sampling depth (cm).

100 ----------- the conversion value from g/cm^2 to t/ha

Water soluble organic carbon (WSOC) calculated with the following formula (Lin, 2010).

$$\text{Water Soluble Organic Carbon (\%)} = c \times (V_0 - V) \times 0.003 \times 1.1 \times 100 / (m_1 \times K_2) \text{----} (6)$$

where;

c ------------ $FeSO_4$ concentration of titration

V_0 ------------ Blank calibration with $FeSO_4$ volume (ml)

V ------------ Titration soil sample with $FeSO_4$ volume (ml)

0.003 ------------ The molar mass of carbon atoms (g/mmol)

1.1 ------------ Oxidation correction coefficient

m_1 ------------ Soil quality (g)

K_2 ------------ Soil conversion to drying soil moisture conversion factor

Ammonium nitrogen (NH_4^+) calculated with the following formula (Lin, 2010).

$$\text{Ammonium nitrogen (mg/kg)} = c \times 2 \times (25 + 5 \times (1 - k)) / (5 \times k) \quad \ldots\ldots\ldots\ldots\ldots(6)$$

where;

c ------------ The value of the nitrogen

k ------------ The water content

Nitrate nitrogen (NO_3^-) calculated with the following formula (Lin, 2010).

$$\text{Nitrate nitrogen (mg/kg)} = c \times (25 + 5 \times (1 - k)) / (5 \times k) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where;

c --------- Check the concentration of nitrogen from working curvec=Uv220-Uv275

k --------- The water content

All results were reported as means ± standard deviations. All the data were analysed by two-way ANOVA with plantation treatments and soil depth as factors. A response of soil physical, a chemical property of each depth to treatments was also evaluated by linear regression and oneway analysis of variance (ANOVA) was used to assess the differences in carbon concentrations and pools among the treatments.

All statistical analyses were performed using SPSS 19 statistical software package (SPSS Inc., Chicago, IL, USA). The difference at $P < 0.05$ level was considered as statistically significant. Figures were drawn using Microsoft Excel software.

4. Results

4.1. Tree biomass and carbon storage

Significant differences were found in biomass ($p<0.05$) among tree organs (Table 5). The highest biomass of stem, branch, leaf and root was recorded in the P plantation, followed by the PR, G, GR and R plantations. The same results were found for above-ground, the below-ground and total biomass of upper storey tree in different plantations (Table 5).

Table 5. The tree biomass of organs in different plantations (values are means ± S.D)

Tree organs	Biomass(t/ha)					ANOVA in response to treatments	
	G	GR	P	PR	R	$F_{regression}$	P
Leaf	$3.61±0.43^c$	$2.37±0.30^b$	$11.29±0.62^e$	$8.23±0.63^d$	$0.00±0.00^a$	393.647	<0.001
Branch	$14.99±3.98^b$	$12.78±0.97^b$	$19.27±1.11^c$	$14.40±1.13^b$	$0.00±0.00^a$	54.931	<0.001
Stem	$44.56±2.02^b$	$33.76±0.85^a$	$62.87±4.20^d$	$56.18±4.73^c$	$30.71±0.07^a$	86.178	<0.001
Above-ground	$63.17±6.29^c$	$48.91±2.03^b$	$93.43±5.93^e$	$78.81±6.49^d$	$30.71±0.07^a$	99.798	<0.001
Root	$16.92±0.86^c$	$11.29±0.38^b$	$20.91±1.44^d$	$17.34±1.65^c$	$0.00±0.00^a$	235.517	<0.001
Total	$80.08±7.12^c$	$60.19±2.41^b$	$114.34±7.37^e$	$96.15±8.15^d$	$30.71±0.07^a$	118.260	<0.001

The results of ANOVA indicated a significant difference in carbon storage ($p<0.05$) among tree organs (Table 6). The highest carbon storage of stem, branch, leaf and root was recorded in the P plantation, followed by the PR, G, GR and R plantations. The same results were found for above-ground, below-ground and total carbon storage of upper storey tree in different plantations (Table 6).

Table 6. Carbon storage in different organs of the trees in different forest plantations (values are means ± S.D)

Tree Parts	Carbon (t/ha)					ANOVA in response to treatments	
	G	GR	P	PR	R	$F_{regression}$	P
Leaf	$1.84±0.22^c$	$1.21±0.15^b$	$5.46±0.30^e$	$3.98±0.31^d$	$0.00±0.00^a$	377.361	<0.001
Branch	$5.16±0.39^c$	$4.01±0.30^b$	$9.69±0.56^e$	$7.24±0.57^d$	$0.00±0.00^a$	301.109	<0.001
Stem	$23.08±1.04^b$	$17.45±0.44^a$	$32.33±2.16^d$	$28.86±2.43^c$	$15.65±0.03^a$	86.376	<0.001
Above-ground	$30.08±1.64^c$	$22.66±0.86^b$	$47.48±3.02^e$	$40.09±3.31^d$	$15.65±0.03^a$	140.563	<0.001
Root	$8.26±0.42^c$	$5.51±0.19^b$	$9.95±0.68^d$	$8.24±0.79^c$	$0.00±0.00^a$	235.500	<0.001
Total	$38.34±2.06^c$	$28.17±1.05^b$	$57.42±3.70^e$	$48.33±4.09^d$	$15.65±0.03^a$	153.594	<0.001

In the same plantation, the biomass and carbon storage of different tree organs also have significant variation, and the order of biomass and carbon storage of different tree organs were stem > root > branch > leaf (Table 5 and 6).

4.2. Biomass production and carbon storage of understory vegetation

Significant differences were found in biomass and carbon storage of the understory vegetation ($p<0.05$) among seasons in the same plantation (Table 7 and 8). The highest biomass and carbon storage of understory vegetation was P system on all season.

Table 7. Biomass of the understory vegetation in different forest plantations (values are means ± S.D)

Seasons	Biomass(t/ha)					ANOVA in response to treatments	
	G	GR	P	PR	R	$F_{regression}$	P
Spring	$0.83±0.10^{c}$	$0.34±0.08^{a}$	$5.59±1.36^{ab}$	$0.10±0.05^{a}$	$0.54±0.07^{b}$	42.568	<0.001
Summer	$0.89±0.11^{c}$	$0.36±0.08^{a}$	$7.89±1.51^{b}$	$0.11±0.05^{a}$	$0.58±0.07^{b}$	72.211	<0.001
Autumn	$0.57±0.07^{b}$	$1.61±0.78^{b}$	$5.58±1.23^{ab}$	$1.37±0.60^{b}$	$0.67±0.35^{b}$	24.715	<0.001
Winter	$0.23±0.10^{a}$	$0.29±0.03^{a}$	$3.55±0.41^{a}$	$0.18±0.08^{a}$	$0.08±0.04^{a}$	182.544	<0.001

The results of ANOVA indicated that a significant difference was found on biomass and carbon storage of understory vegetations for five plantations in the same season. In all seasons, P plantation obtained highest understory biomass and sequestrated more understory carbon in comparison to the other plantations (Table 5 & 6).

Table 8. Carbon storage of understory vegetation in different forest plantations (values are means ± S.D)

Seasons	Carbon (t/ha)					ANOVA in response to treatments	
	G	GR	P	PR	R	$F_{regression}$	P
Spring	$0.35±0.04^{c}$	$0.14±0.03^{a}$	$2.37±0.58^{ab}$	$0.04±0.02^{a}$	$0.23±0.03^{b}$	42.568	<0.001
Summer	$0.38±0.05^{c}$	$0.15±0.04^{a}$	$3.35±0.04^{b}$	$0.05±0.02^{a}$	$0.24±0.03^{b}$	72.211	<0.001
Autumn	$0.24±0.03^{b}$	$0.68±0.33^{b}$	$2.37±0.52^{ab}$	$0.58±0.26^{b}$	$0.28±0.15^{b}$	24.715	<0.001
Winter	$0.10±0.04^{a}$	$0.12±0.01^{a}$	$1.50±0.17^{a}$	$0.08±0.03^{a}$	$0.04±0.02^{a}$	182.544	<0.001

4.3. Soil physical properties

4.3.1 Soil bulk

Soil bulk changed accordingly with the variation of a managing system, soil depth and season (Figure 3). Soil bulk increased with the increasing of soil depth in all managing system of spring, summer and autumn. However, in winter, soil bulk obtained the highest value in the soil layer 20-40cm for G, GR, P and PR system, and soil bulk of topsoil lowered than the 10-20cm layer in G, P, PR and R system. In all seasons, soil bulk of 20-40cm, 40-60cm and 60-100cm had little difference in the same managing system. The results of ANOVA showed that soil bulk of different soil depth had significant variation in all seasons (Table 9-12).

Table 9. Results of analysis of variance for soil physical and chemical properties in plantations of different treatments and at different soil depths (Spring)

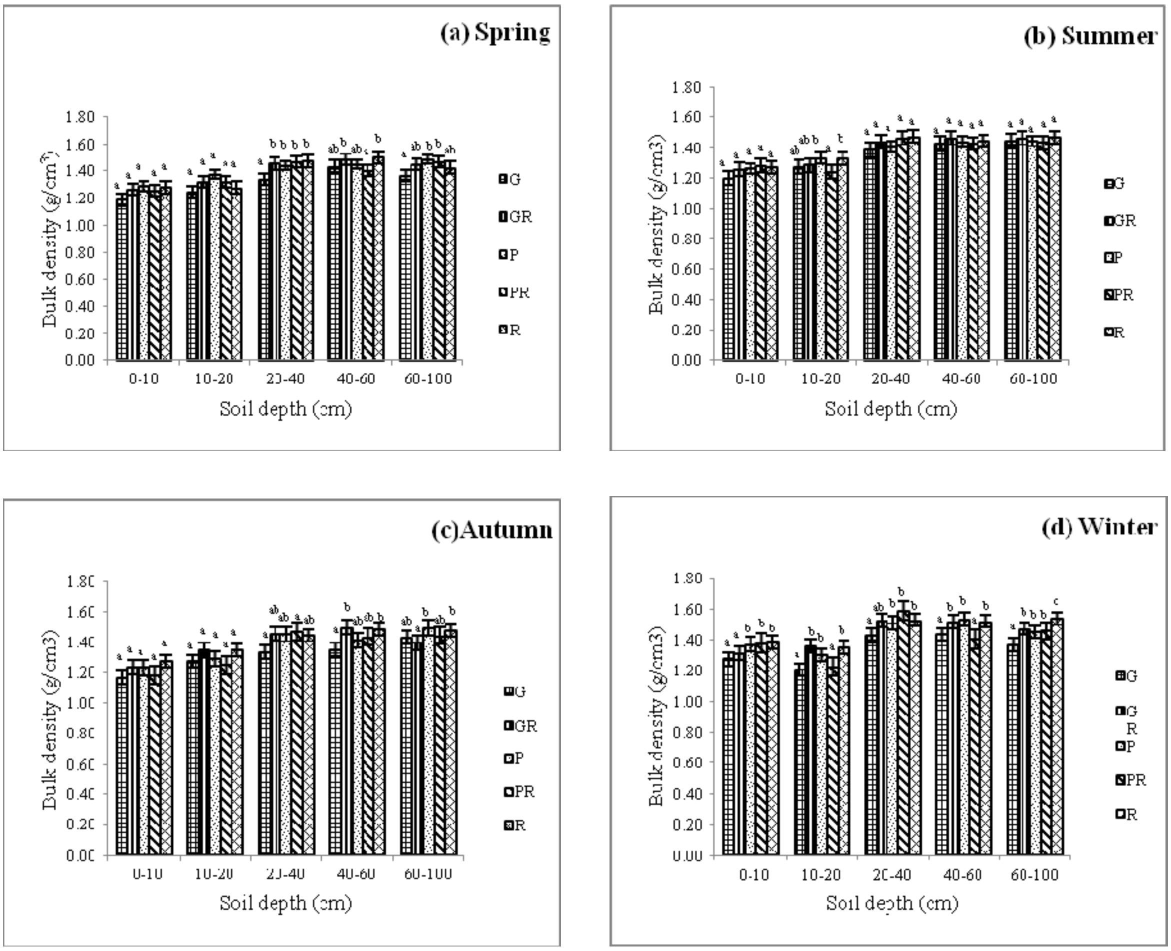
Index	Treatment		Soil depth		Treatment x Soil depth	
	F	P	F	P	F	P
Bulk density (g/cm^3)	34.664	<0.001	23.016	<0.001	1.628	0.206
Maximum water-holding capacity (%)	4.791	0.002	39.166	<0.001	1.073	0.404
Available water-holding capacity (%)	1.795	0.144	28.625	<0.001	0.889	0.585
Water Content (%)	88.549	<0.001	6.017	<0.001	5.344	<0.001
pH	6.738	<0.001	29.887	<0.001	0.800	0.679
SOC content (g/Kg)	13.408	<0.001	55.065	<0.001	0.971	0.501
Soil carbon storage (t/ha)	13.126	<0.001	12.087	<0.001	1.968	0.035
Soil Active Organic Carbon (mg/g)	2.745	0.038	140.661	<0.001	6.485	<0.001
Water Soluble Organic Carbon (mg/Kg)	8.197	<0.001	1.290	0.286	1.532	0.126
Microbial Organic Carbon (mg/Kg)	4.317	0.004	0.881	0.482	1.226	0.283
Available Nitrogen (mg/Kg)	15.619	<0.001	30.282	<0.001	3.250	<0.001
Nitrate Nitrogen (mg/Kg)	11.319	<0.001	5.664	<0.001	1.472	0.148
Ammonium Nitrogen (mg/Kg)	11.907	<0.001	27.739	<0.001	2.835	0.003

Table 10. Results of analysis of variance for soil physical and chemical properties in plantations of different treatments and at different soil depths (Summer)

Index	Treatment		Soil depth		Treatment x Soil depth	
	F	P	F	P	F	P
Bulk density (g/cm^3)	1.491	0.236	10.712	<0.001	0.267	0.896
Maximum water-holding capacity (%)	0.103	0.752	6.852	0.001	0.718	0.589
Available water-holding capacity (%)	20.726	<0.001	2.205	0.105	1.513	0.236
Water Content (%)	13.832	<0.001	40.155	<0.001	2.111	0.023
pH	1.232	0.309	32.605	<0.001	1.014	0.458
SOC content (g/Kg)	10.935	<0.001	121.188	<0.001	1.556	0.118
Soil carbon storage (t/ha)	10.465	<0.001	10.798	<0.001	0.877	0.598
Soil Active Organic Carbon (mg/g)	1.320	0.276	42.184	<0.001	1.078	0.400
Water Soluble Organic Carbon (mg/Kg)	0.858	0.496	4.242	0.005	0.396	0.977
Microbial Organic Carbon (mg/Kg)	1.511	0.213	0.701	0.595	0.477	0.947
Available Nitrogen (mg/Kg)	34.791	<0.001	12.669	<0.001	5.540	<0.001
Nitrate Nitrogen (mg/Kg)	32.523	<0.001	10.448	<0.001	6.594	<0.001
Ammonium Nitrogen (mg/Kg)	10.708	<0.001	4.178	0.005	1.578	0.111

Soil bulk of the same soil layer was different in five managing system (Figure 3). G system had lowest soil bulk in different soil layer of four seasons, and R system obtained higher soil bulk in 0-10cm and 10-20cm soil layer. Soil bulk of 40-60cm, 60-80cm and 80-100cm had little difference among five managing system. The results of ANOVA showed that soil bulk of different managing system had significant variation in spring, autumn and winter (Table 9-12).

Soil bulk also changed with the difference of season, especially topsoil (Figure 3). Soil bulk of 0-10cm layer in winter was highest in five managing system, and it had a little variation in other three seasons.



Note: Different letters indicate the significant differences in soil bulk density among the soil depth according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 3. Comparison of soil bulk density among soil depths of different treatments

Table 11. Results of analysis of variance for soil physical and chemical properties in plantations of different treatments and at different soil depths (Autumn)

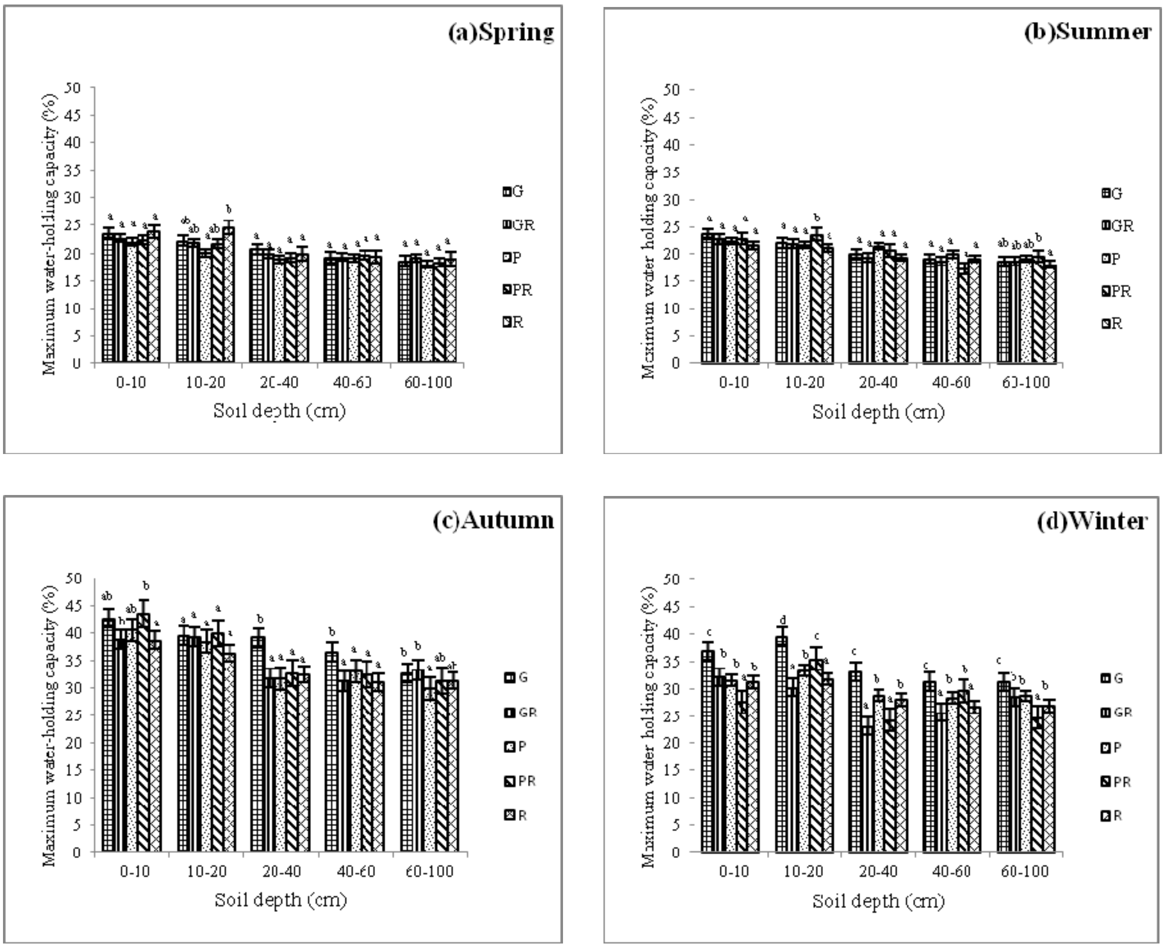
Index	Treatment		Soil depth		Treatment x Soil depth	
	F	P	F	P	F	P
Bulk density (g/cm^3)	7.391	<0.001	61.408	<0.001	1.556	0.118
Maximum water-holding capacity (%)	1.584	0.193	0.607	0.659	0.284	0.996
Available water-holding capacity (%)	5.460	<0.001	33.298	<0.001	1.031	0.443
Water Content (%)	2.893	0.031	1.080	0.377	1.132	0.353
pH	8.779	<0.001	29.306	<0.001	0.568	0.892
SOC content (g/Kg)	10.337	<0.001	64.010	<0.001	1.473	0.148
Soil carbon storage	16.090	<0.001	19.690	<0.001	2.053	0.027
Soil Active Organic Carbon (mg/g)	1.823	0.139	57.443	<0.001	1.848	0.050
Water Soluble Organic Carbon (mg/Kg)	1.096	0.369	1.504	0.215	0.735	0.745
Microbial Organic Carbon (mg/Kg)	10.825	<0.001	3.426	0.015	1.612	0.100
Available Nitrogen (mg/Kg)	5.205	0.001	2.289	0.073	1.326	0.219
Nitrate Nitrogen (mg/Kg)	35.965	<0.001	8.176	<0.001	6.755	<0.001
Ammonium Nitrogen (mg/Kg)	0.999	0.417	0.805	0.528	0.581	0.883

Table 12. Results of analysis of variance for soil physical and chemical properties in plantations of different treatments and at different soil depths (Winter)

Index	Treatment		Soil depth		Treatment x Soil depth	
	F	P	F	P	F	P
Bulk density (g/cm^3)	25.450	<0.001	111.511	<0.001	4.288	<0.001
Maximum water-holding capacity (%)	82.603	<0.001	99.391	<0.001	9.597	<0.001
Available water-holding capacity (%)	65.527	<0.001	43.612	<0.001	11.238	<0.001
Water Content (%)	18.376	<0.001	7.540	<0.001	2.464	0.008
pH	37.730	<0.001	73.825	<0.001	7.985	<0.001
SOC content (g/Kg)	23.262	<0.001	683.075	<0.001	13.654	<0.001
Soil carbon storage (t/ha)	26.813	<0.001	68.321	<0.001	11.534	<0.001
Soil Active Organic Carbon (mg/g)	4.862	0.002	59.826	<0.001	4.128	<0.001
Water Soluble Organic Carbon (mg/Kg)	16.275	<0.001	106.990	<0.001	5.915	<0.001
Microbial Organic Carbon (mg/Kg)	25.560	<0.001	415.516	<0.001	165.319	<0.001
Available Nitrogen (mg/Kg)	6.810	<0.001	1.740	0.156	4.911	<0.001
Nitrate Nitrogen (mg/Kg)	2.953	0.029	5.905	<0.001	1.293	0.239
Ammonium Nitrogen (mg/Kg)	6.477	<0.001	2.219	0.080	6.663	<0.001

4.3.2 Soil water

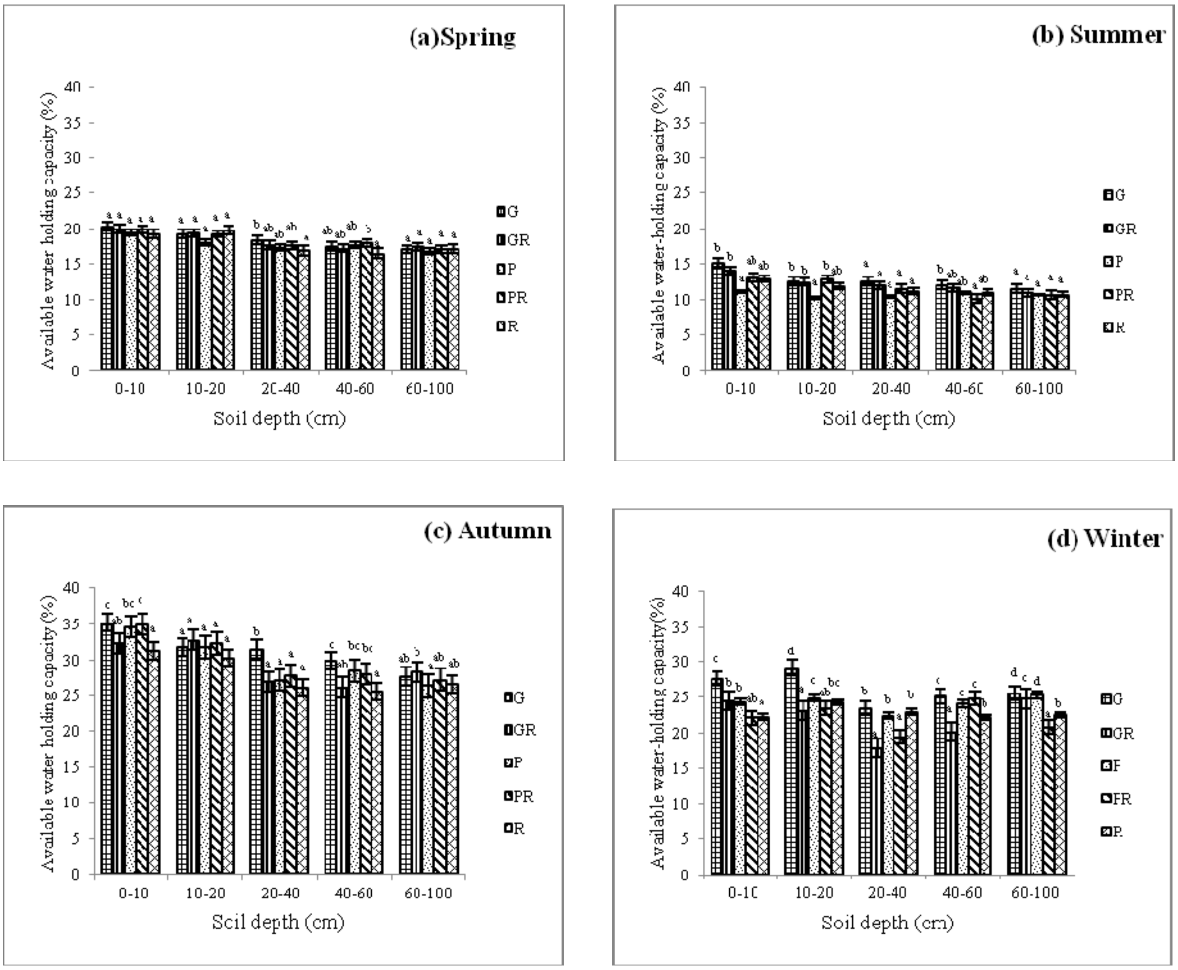
Soil water such as maximum water-holding capacity, available water holding capacity and water content changed accordingly with the variation of a managing system, soil depth and season (Figure 4-6). Maximum and available water-holding capacity decreased with the increasing of soil depth in all managing system of spring, summer and autumn. However, in winter, maximum and available water-holding capacity obtained the highest value in the soil layer 10-20cm for G, P, PR and R system, and maximum and available water-holding capacity of topsoil higher than the 10-20cm layer in G, P, PR and R systems.



Note: Different letters indicate the significant differences in maximum water-holding capacity among the soil depth according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 4. Comparison of maximum water-holding capacity among soil depths of different treatments

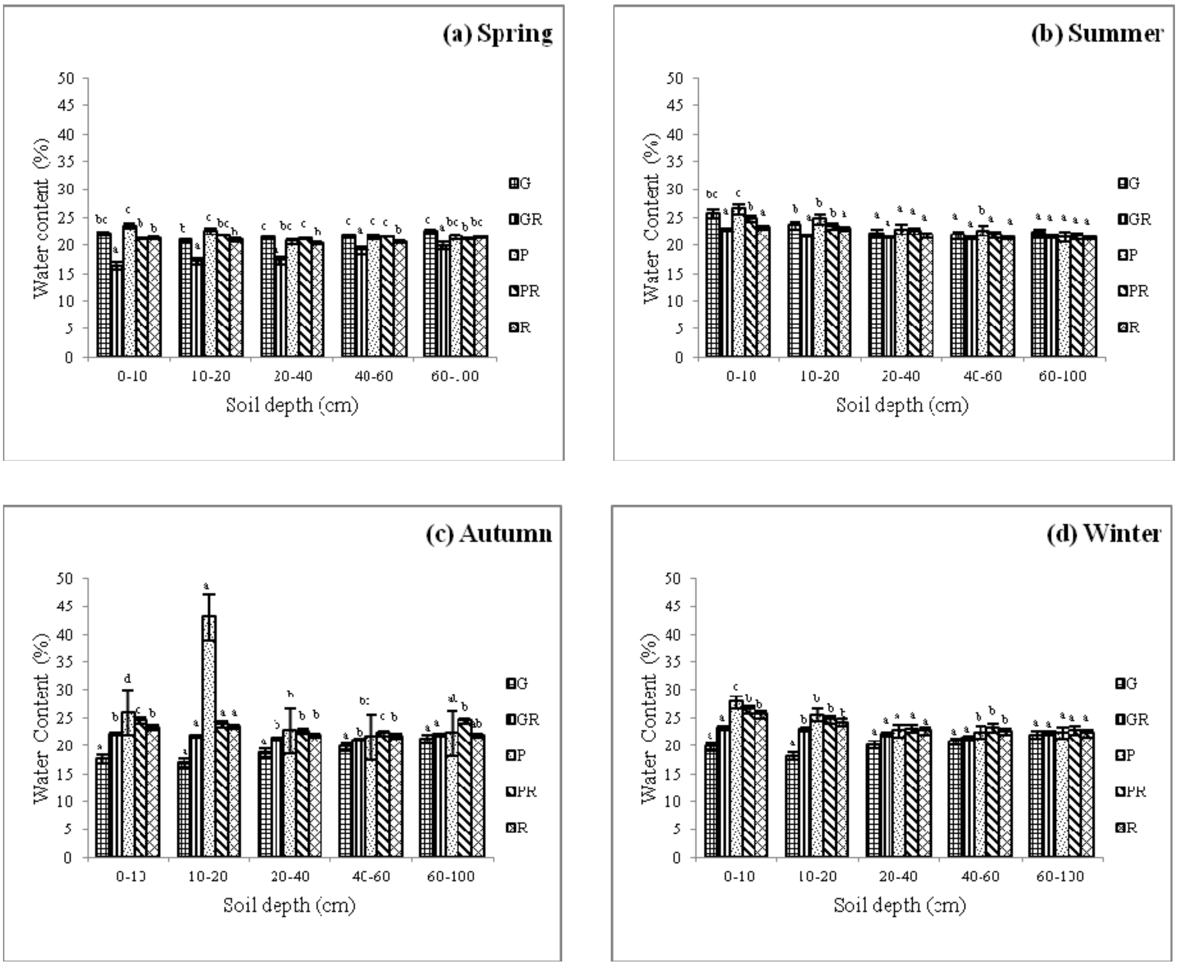
In all seasons, maximum and available water-holding capacity of 40-60cm and 60-100cm had little difference in the same managing system. The results of ANOVA showed that maximum water-holding capacity of different soil depth had significant variation in spring and winter and available water-holding capacity of different soil depth had significant variation in spring, autumn and winter season. But water content decreased with the increasing of soil depth in all managing system of all seasons.



Note: Different letters indicate the significant differences in available water-holding capacity among the soil depth according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 5. Comparison of available water-holding capacity among soil depths of different treatments

In autumn, water content obtained highest value in the soil layer 10-20cm layer P system and water content of topsoil also higher than the 10-20cm layer in P system. In all seasons, the water content of 20-40cm, 40-60cm and 60-100cm had little difference in the same managing system. The results of ANOVA showed that water content of different soil depth had significant variation in spring, summer and winter season (Table 9-12).



Note: Different letters indicate the significant differences in water content among the soil depth according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 6. Comparison of water content among soil depths of different treatments

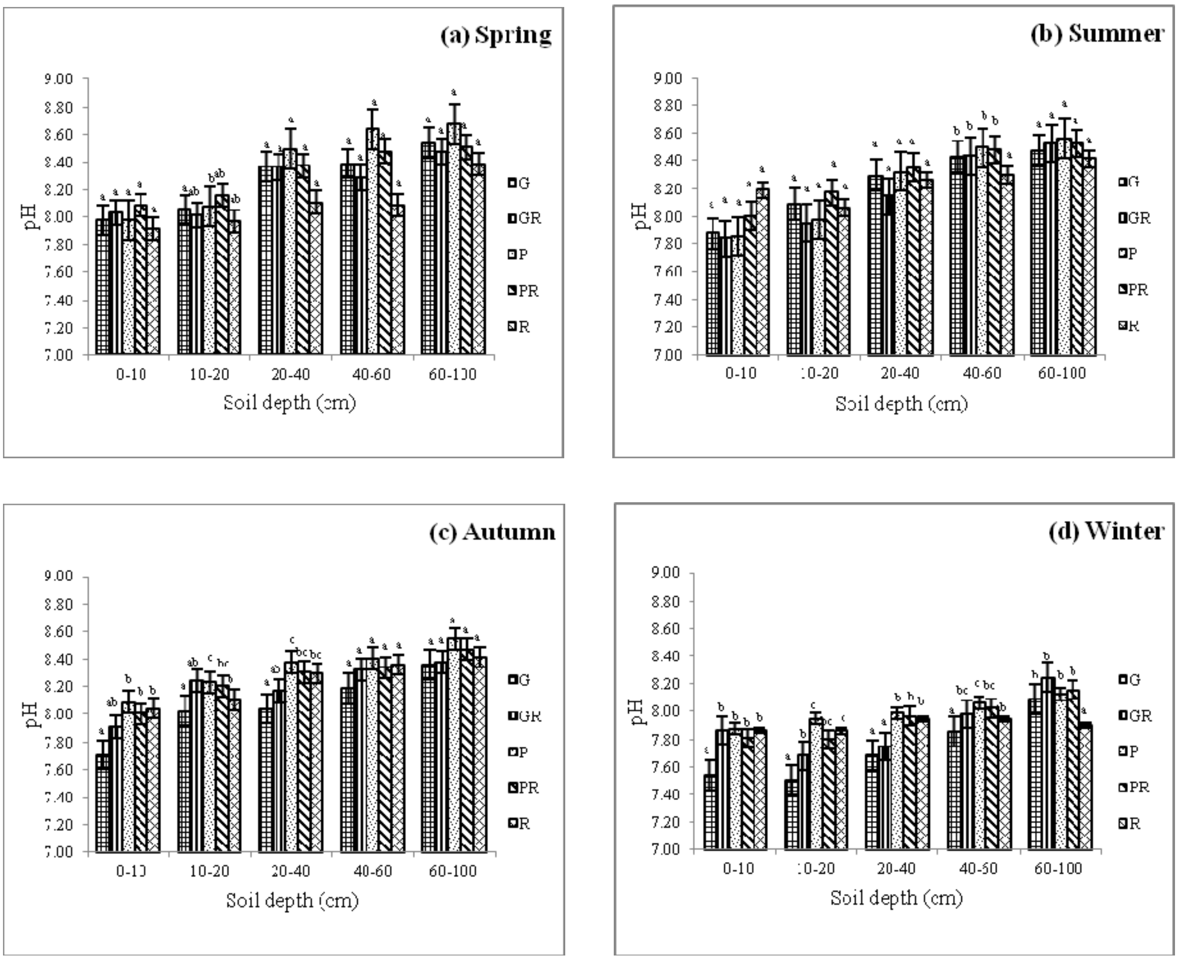
Soil water of the same soil layer was different in five managing system (Figure 4-6). Maximum and available water-holding capacity of P system had lowest in different soil layer of spring and summer seasons and R system had lowest in autumn and winter seasons. Maximum and available water-holding capacity of G system obtained higher in 0-10cm and 10-20cm soil layer. Maximum and available water-holding capacity of 20-40cm, 40-60cm and 60-100cm had little difference among five managing system. The results of ANOVA showed that maximum water-holding capacity of different managing system had significant variation in winter and available water-holding capacity of different managing system had significant variation in summer, autumn and winter. The water content of GR system had lowest in different soil layer of spring and summer seasons and G system had lowest in autumn and winter seasons. The water content of P system obtained higher in the 0-10cm and 10-20cm soil layer. The water content of 40-60cm, 60-80cm and 80-100cm had little difference among five managing system. The results of ANOVA showed that water content of different managing system had significant variation in spring, summer and winter (Table 9-12).

Soil water also changed with the difference of season, especially topsoil (Figure 4-6). Maximum and available water-holding capacity of the 0-10cm layer and water content of the 10-20cm layer in autumn was highest in five managing system, and it had a little variation in other three seasons.

4.4 Soil chemical properties

4.4.1 Soil pH

Soil pH also changed accordingly with the variation of a managing system, soil depth and season (Figure 7). Soil pH increased with the increasing of soil depth in all managing system of all seasons. The highest soil pH value found in the soil layer 60-100cm for G and P system in spring, and soil pH of topsoil lowered than the 10-20cm layer for G, GR, PR and R system in winter. In all seasons, soil pH of 20-40cm, 40-60cm and 60-100cm had little difference in the same managing system. The results of ANOVA showed that soil pH of different soil depth had significant variation in all seasons (Table 9-12).



Note: Different letters indicate the significant differences in soil pH among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 7. Comparison of soil pH among the soil depths of different treatments

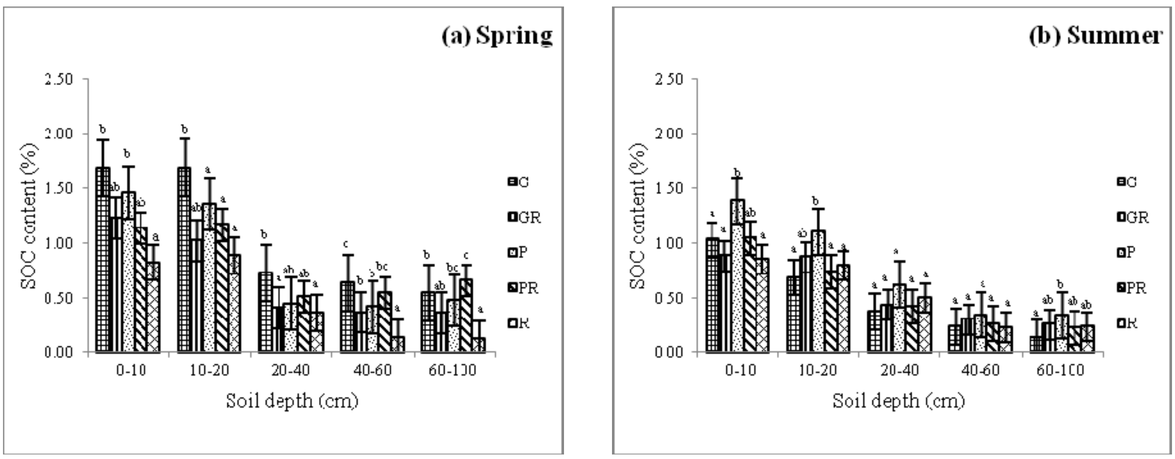
Soil pH of the same soil layer was different in five managing system (Figure 7). Soil pH of R system had lowest in different soil layer of spring, GR system in different soil layer of summer, and G system in different soil layer of autumn and winter seasons. But PR system obtained higher soil pH of spring and summer and P system obtained higher soil pH of autumn and winter in the 0-10cm and 10-20cm soil layer. Soil pH of 40-60cm, 60-80cm and 80-100cm had little difference among five managing system. The results of ANOVA showed that soil pH of different managing system had significant variation in spring, autumn and winter (Table 9-12).

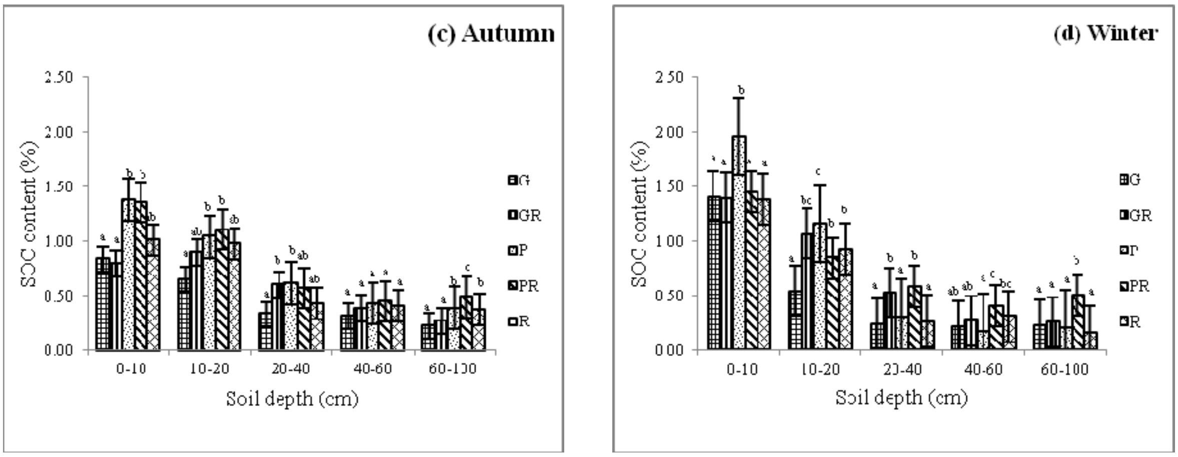
Soil pH also changed with the difference of season, especially topsoil (Figure 7). Soil pH of the 0-10cm layer in spring was highest in five managing system, and it had a little variation in other three seasons.

4.4.2 Soil organic carbon

Soil organic carbon (SOC) content changed accordingly with the variation of a managing system, soil depth and season (Figure 8). SOC content decreased with the increasing of soil depth in all managing system of all seasons. SOC content obtained the highest value in the soil layer 0-10cm and 10-20cm layer for G system in spring and for P system in summer, autumn and winter seasons, and SOC content of topsoil higher than the 10-20cm layer in G, PR and R system. In all seasons, SOC content of 20-40cm, 40-60cm and 60-100cm had also quite difference in the same managing system. The results of ANOVA showed that SOC content of different soil depth had significant variation in all seasons (Table 9-12).

Soil organic carbon content of the same soil layer was different in five managing system (Figure 8). SOC content of R system had lowest in different soil layer and G system obtained higher SOC in 0-10cm and 10-20cm soil layer of spring but G system had lowest in different soil layer and P system obtained higher SOC content in the 0-10cm and 10-20cm soil layer of summer, autumn and winter seasons. SOC content of 20-40cm, 40-60cm and 60-100cm had little difference among five managing system. The results of ANOVA showed that SOC content of different managing system had significant variation in all seasons (Table 9-12).



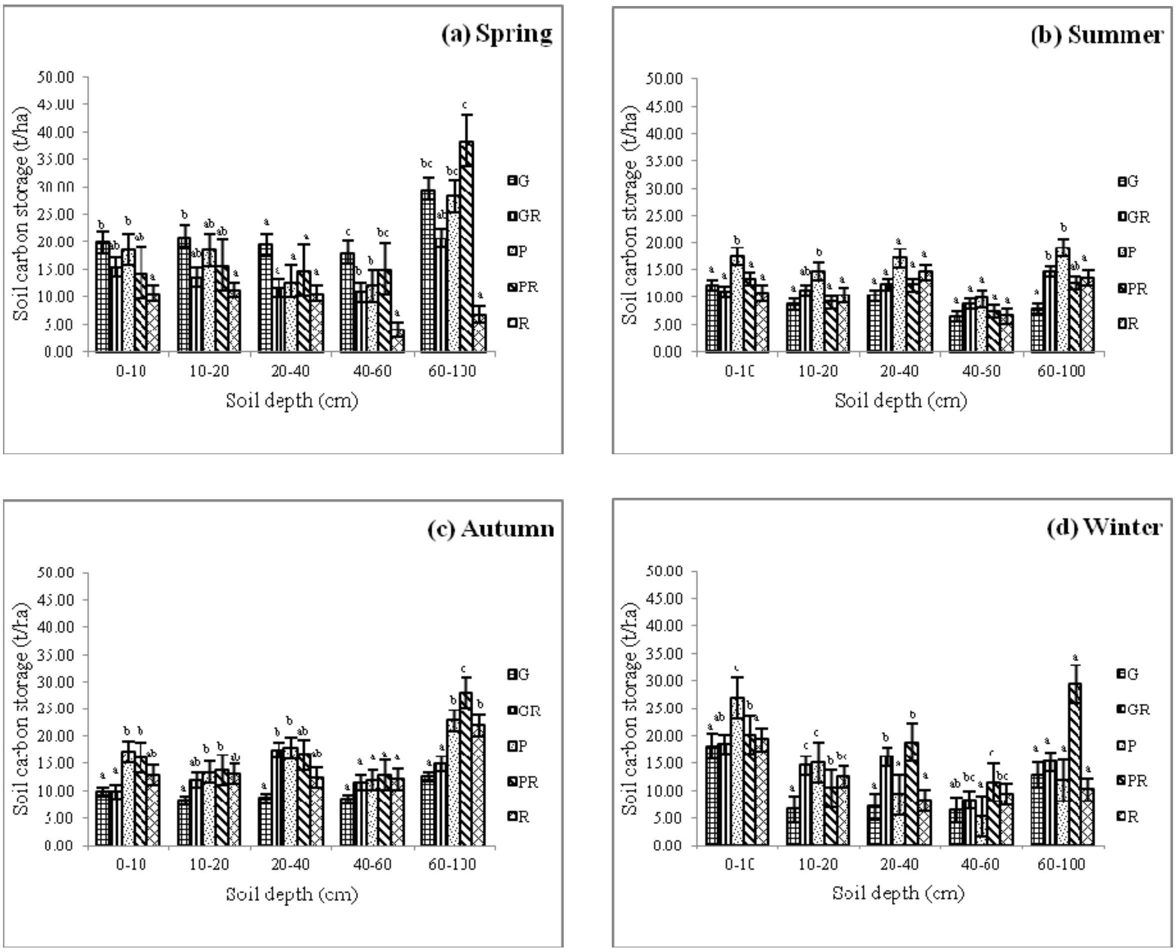


Note: Different letters indicate the significant differences in SOC among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 8. Comparison of soil organic carbon among the soil depths of different treatments

SOC content also changed with the difference of season, especially topsoil (Figure 8). SOC content of the 0-10cm layer in winter was highest in five managing system, and it had also a quite variation in other three seasons.

Soil carbon storage changed accordingly with the variation of a managing system, soil depth and season (Figure 9). Soil carbon storage varied with the increasing of soil depth in all managing system of all seasons. Soil carbon storage obtained the highest value in the soil layer 0-10cm and 10-20cm layer for G system in spring and for P system in summer, autumn and winter seasons, and soil carbon storage of topsoil higher than the 10-20cm layer in GR in spring and lower than in summer, autumn and winter. In all seasons, soil carbon storage of 20-40cm, 40-60cm and 60-100cm had also quite difference in the same managing system. The results of ANOVA showed that soil carbon storage of different soil depth had significant variation in all seasons (Table 9-12).



Note: Different letters indicate the significant differences in soil carbon storage among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 9. Comparison of soil carbon storage among the soil depths of different treatments

Soil carbon storage of the same soil layer was different in five managing system (Figure 8). Soil carbon storage of R system had lowest in different soil layer in spring and G is the lowest in others and G system obtained higher soil carbon storage in the 0-10cm and 10-20cm soil layer of spring but G system had lowest in different soil layer and P system obtained higher soil carbon storage in the 0-10cm and 10-20cm soil layer of summer, autumn and winter seasons. Soil carbon storage of 20-40cm, 40-60cm and 60-100cm had little difference among five managing system. The results of ANOVA showed that soil carbon storage of different managing system had significant variation in all seasons (Table 9-12).

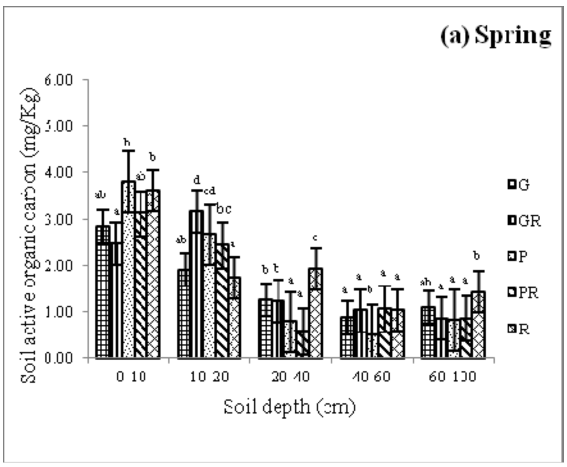
Soil carbon storage also changed with the difference of season, especially topsoil (Figure 9). Soil carbon storage of the 0-10cm layer in winter was highest in five managing system, and it had also a quite variation in other three seasons.

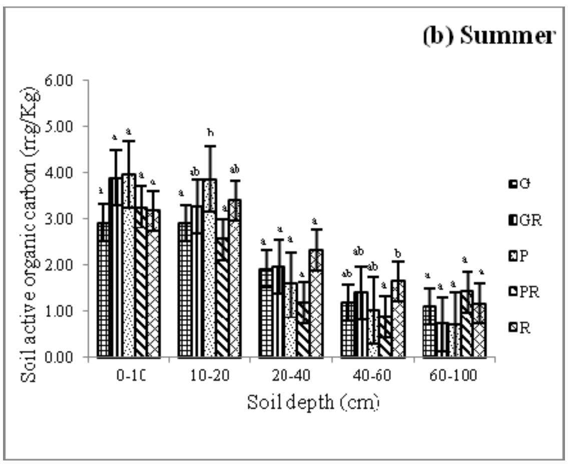
4.4.3 Soil organic carbon fraction

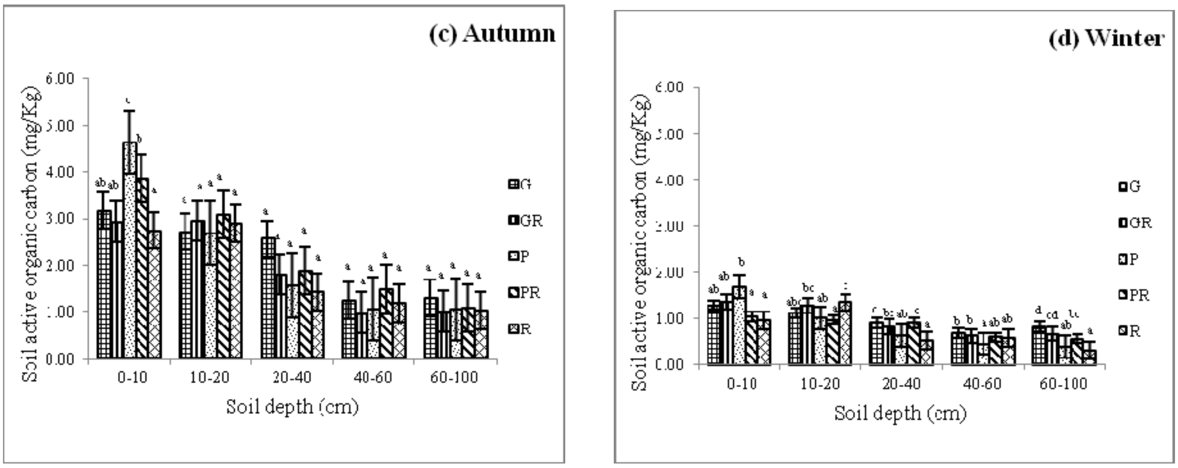
Soil active organic carbon(SAOC) changed accordingly with the variation of a managing system, soil depth and season (Figure 10). SAOC decreased with the increasing of soil depth in all managing system of all seasons. SAOC obtained the highest value in the soil layer 0-10cm for G, P and PR system in autumn, and SAOC of topsoil higher than the 10-20cm layer in R system of all seasons. In all seasons, SAOC of 20-40cm, 40-60cm and 60-100cm had quite difference in the same managing system. The results of ANOVA showed that SAOC of different soil depth had significant variation in all seasons (Table 9-12).

SAOC of the same soil layer was different in five managing system (Figure 10). G system had lowest SAOC in different soil layer of spring and summer and R system in autumn and winter seasons, and P system obtained higher SAOC in the 0-10cm and 10-20cm soil layer. SAOC of 40-60cm, 60-80cm and 80-100cm had little difference among five managing system. The results of ANOVA showed that SAOC of different managing system had significant variation in spring and winter (Table 9-12).

SAOC also changed with the difference of season, especially topsoil (Figure 10). SAOC of the 0-10cm layer in autumn was highest in five managing system, and it had also a quite variation in other three seasons.







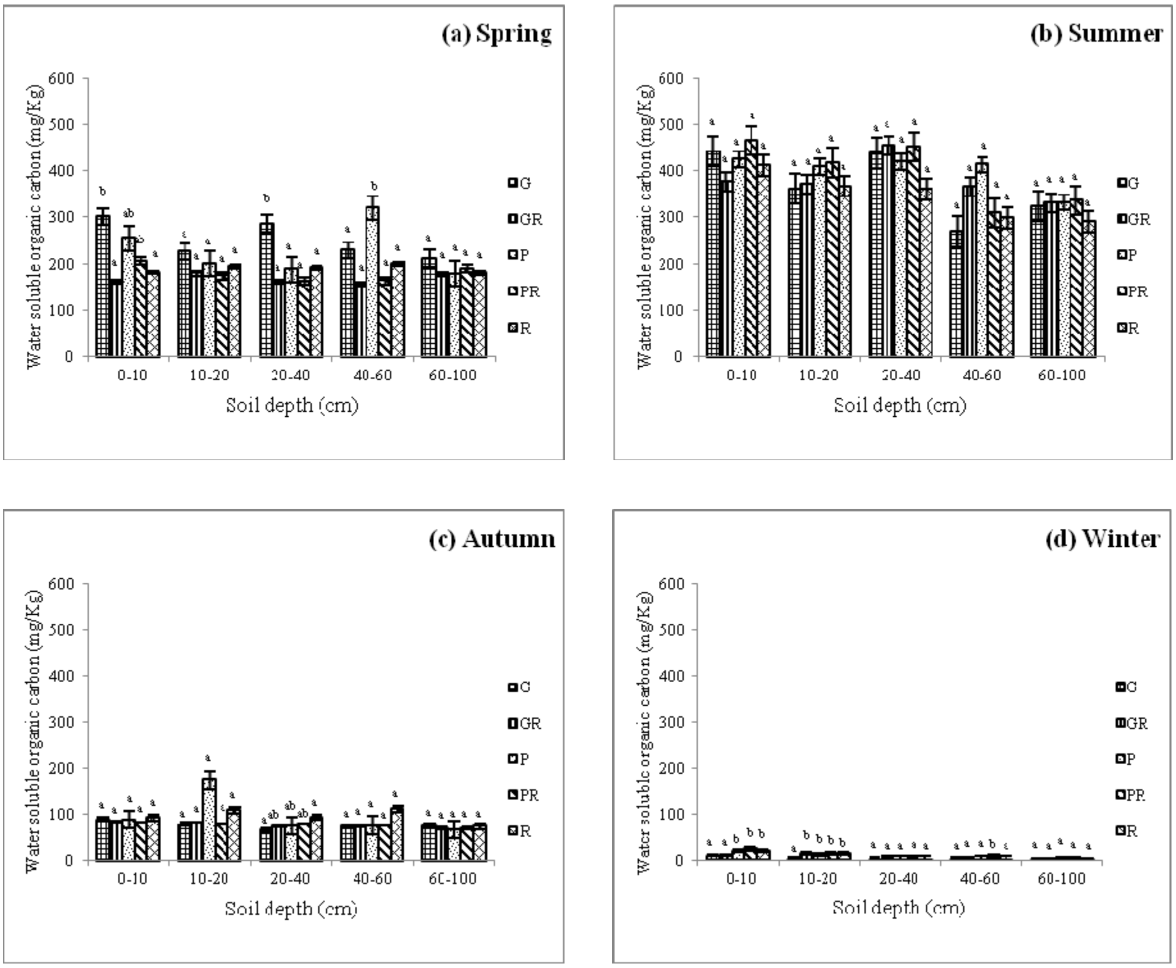
Note: Different letters indicate the significant differences in ASOC among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 10. Comparison of soil active organic carbon among the soil depths of different treatments

Water soluble organic carbon(WSOC) changed accordingly with the variation of a managing system, soil depth and season (Figure 11). WSOC decreased with the increasing of soil depth in all managing system of all seasons. WSOC obtained the highest value in the soil layer 0-10cm for all managing system in summer and WSOC of topsoil higher than the 10-20cm layer in P and R systems in autumn. In all seasons, WAOC of 20-40cm, 40-60cm and 60-100cm had quite difference in the same managing system. The results of ANOVA showed that WSOC of different soil depth had significant variation in winter (Table 9-12).

WSOC of the same soil layer was different in five managing system (Figure 11). GR system had lowest WSOC in different soil layer of spring and summer and G system in autumn and winter seasons, and G system in spring, P system in autumn and PR system in summer and winter obtained higher WSOC in 0-10cm and 10-20cm soil layer. SWOC of 20-40cm, 40-60cm and 60-100cm had quite difference among five managing system. The results of ANOVA showed that WSOC of different managing system had significant variation in spring and winter (Table 9-12).

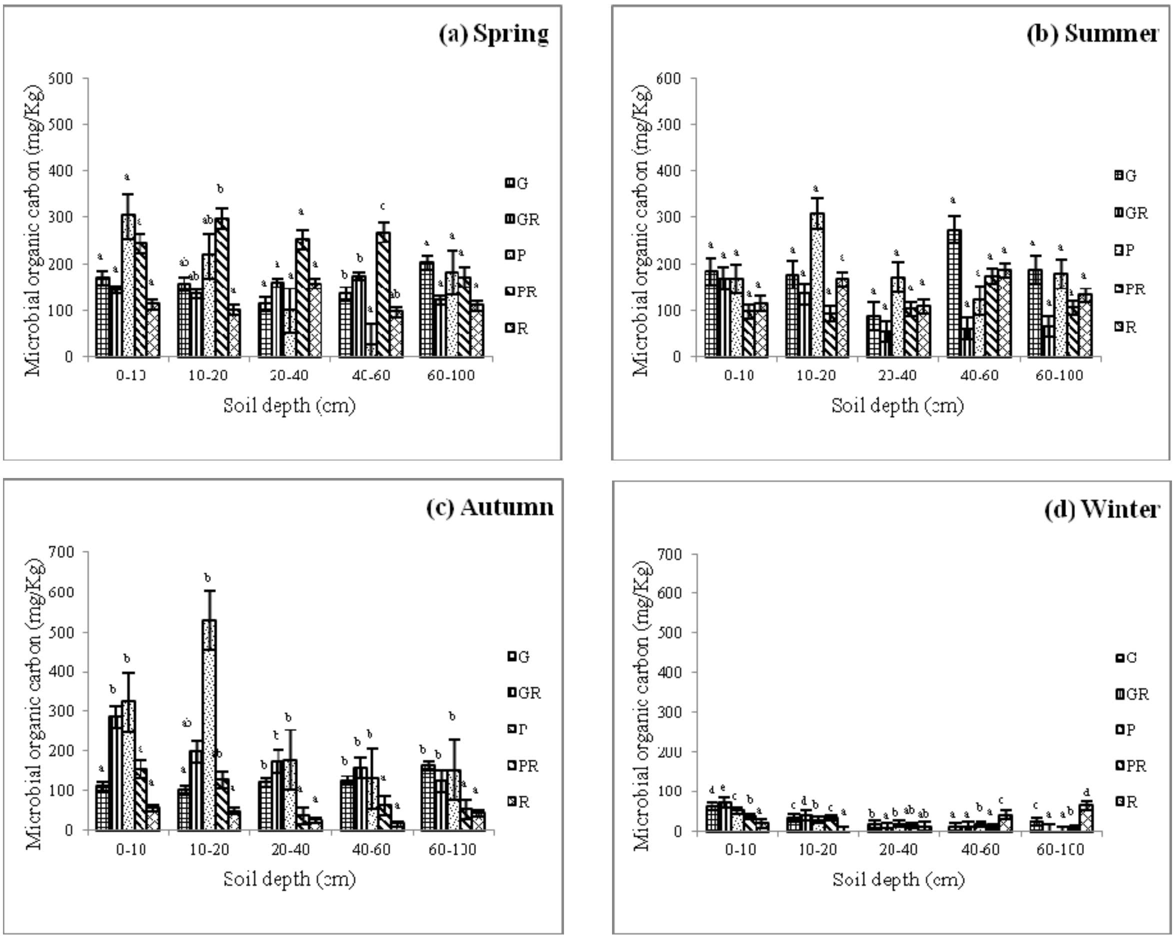
WSOC also changed with the difference of season, especially topsoil (Figure 11). WSOC of the 0-10cm layer in summer was highest in five managing system, and it had a little variation in other three seasons.



Note: Different letters indicate the significant differences in WSOC among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 11. Comparison of water soluble organic carbon among the soil depths of different treatments

Microbial organic carbon (MBOC) changed accordingly with the variation of a managing system, soil depth and season (Figure 12). MBOC was unstable with the increasing of soil depth in all managing system of all seasons. MBOC obtained the highest value in the soil layer 0-10cm for P system in autumn, and MBOC of topsoil lowered than the 10-20cm layer in P and R systems in summer. In all seasons, MBOC of 20-40cm, 40-60cm and 60-100cm had quite difference in the same managing system. The results of ANOVA showed that MBOC of different soil depth had significant variation only in the winter season (Table 9-12).



Note: Different letters indicate the significant differences in MBOC among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 12. Comparison of microbial organic carbon among the soil depths of different treatments

MBOC of the same soil layer was different in five managing system (Figure 12). R system had lowest MBOC in different soil layer of the autumn season, and P system obtained higher MBOC in 0-10cm and 10-20cm soil layer. MBOC of 20-40cm, 40-60cm and 60-100cm had quite difference among five managing system. The results of ANOVA showed that MBOC of different managing system had significant variation in autumn and winter (Table 9-12).

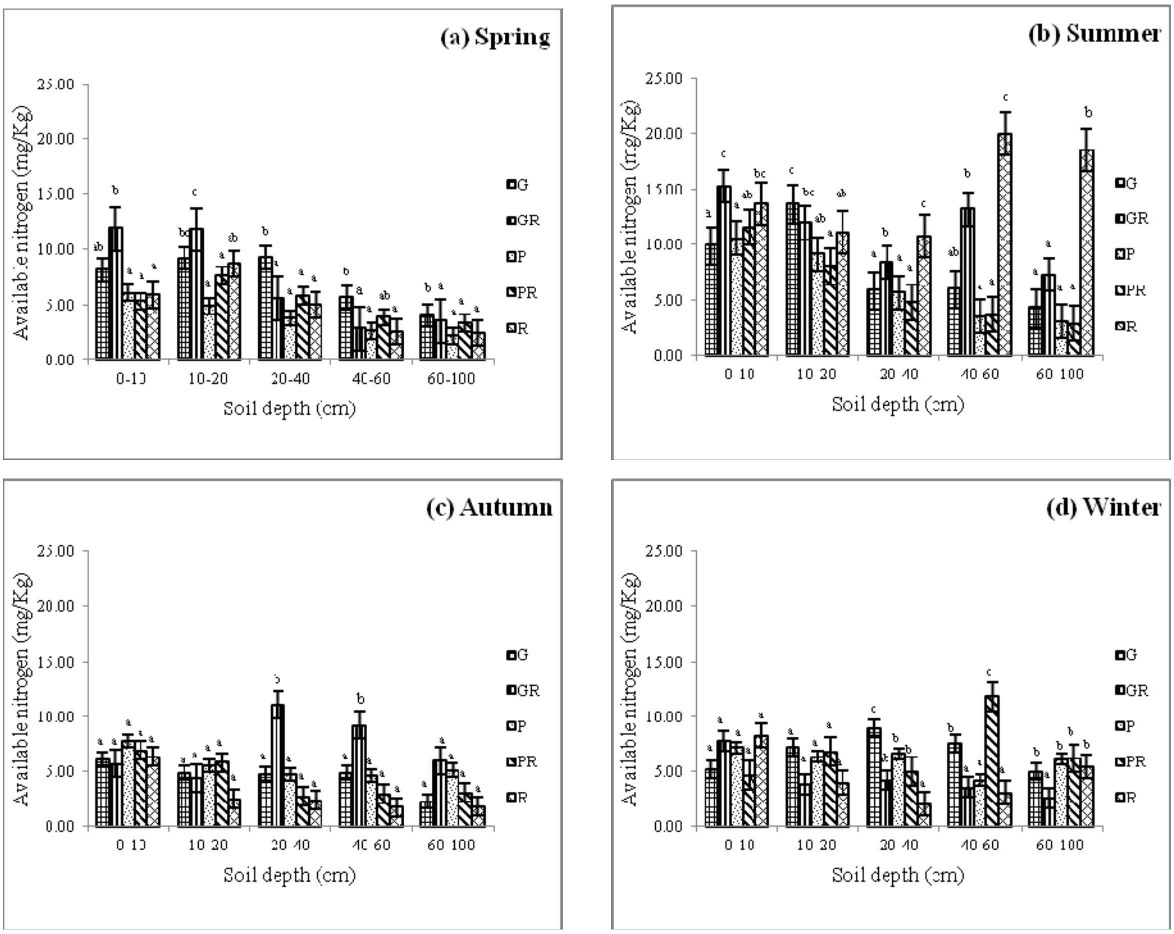
MBOC also changed with the difference of season, especially topsoil (Figure 12). MBOC of the 10-20cm layer in autumn was highest in five managing system, and it had a quite variation in other three seasons.

4.4.4 Soil nitrogen

Soil available nitrogen changed accordingly with the variation of a managing system, soil depth and season (Figure 13). Available N decreased with the increasing of soil depth in all managing system of spring but not in other seasons. However, in summer, available N obtained the highest value in the soil layer 40-60cm for R system, and available N of topsoil higher than the 10-20cm layer in G, GR, PR and R system in spring. In all seasons, available N of 20-40cm, 40-60cm and 60-100cm had a high difference in the same managing system. The results of ANOVA showed that available N of different soil depth had significant variation in spring and summer (Table 9-12).

Soil available nitrogen of the same soil layer was different in five managing system (Figure 13). R system had lowest soil bulk in different soil layer of the autumn season, and GR system obtained higher soil bulk in the 0-10cm and 10-20cm soil layer. Soil bulk of 20-40cm, 40-60cm and 60-100cm had high difference among five managing system. The results of ANOVA showed that available N of different managing system had significant variation in spring, summer and winter (Table 9-12).

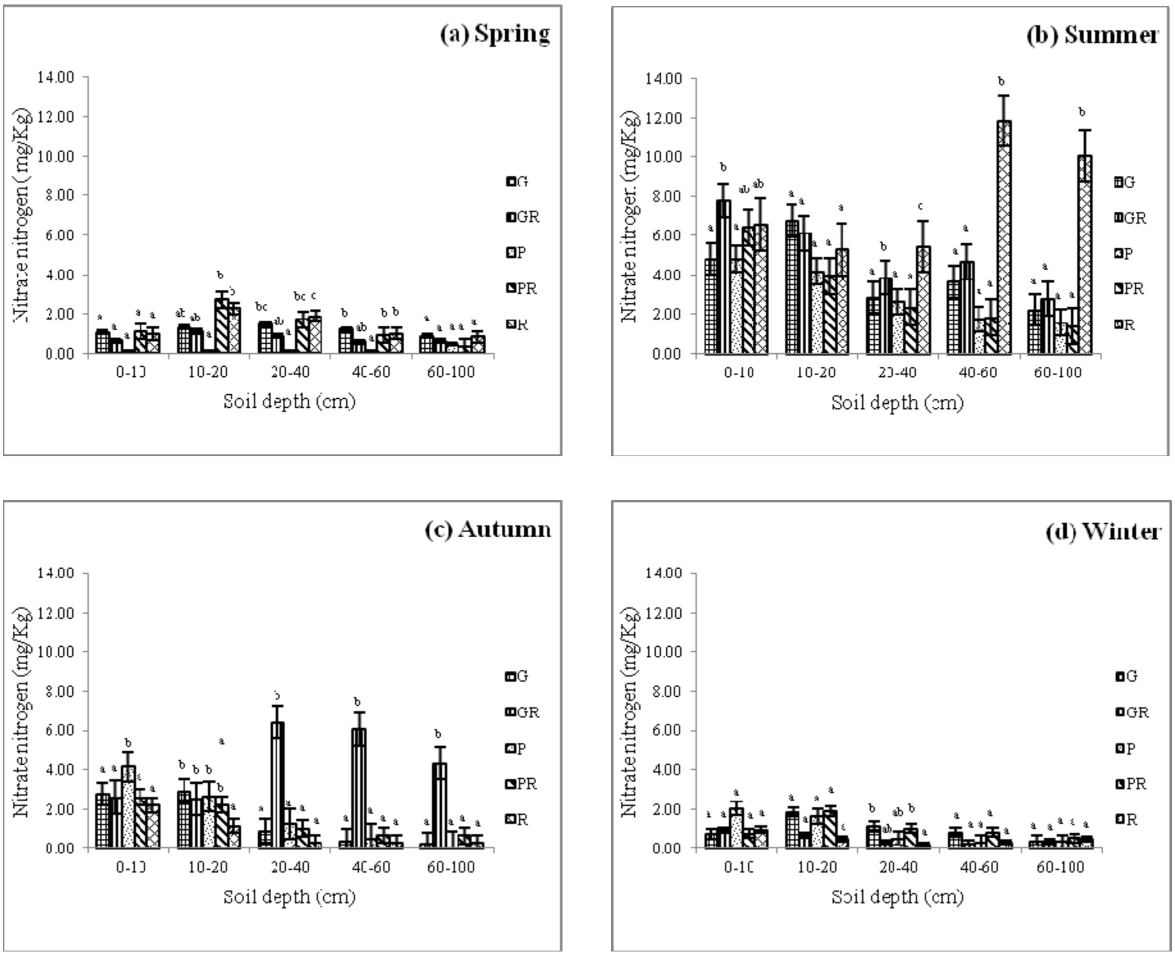
Soil available nitrogen also changed with the difference of season, especially topsoil (Figure 13). Available N of the 40-60cm layer in summer was highest in five managing system, and it had a high variation in other three seasons.



Note: Different letters indicate the significant differences in available nitrogen among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 13. Comparison of available nitrogen among the soil depths of different treatments

Soil nitrate nitrogen(NO_3^-) changed accordingly with the variation of a managing system, soil depth and season (Figure 14). NO_3^- decreased with the increasing of soil depth in all managing system of winter but not in other seasons. However, in summer, NO_3^- obtained the highest value in the soil layer 40-60cm for R system, and NO_3^- of topsoil higher than the 10-20cm layer in G, GR, PR and R system in spring. In all seasons, available N of 20-40cm, 40-60cm and 60-100cm had a high difference in the same managing system. The results of ANOVA showed that NO_3^- of different soil depth had significant variation in all seasons (Table 9-12).

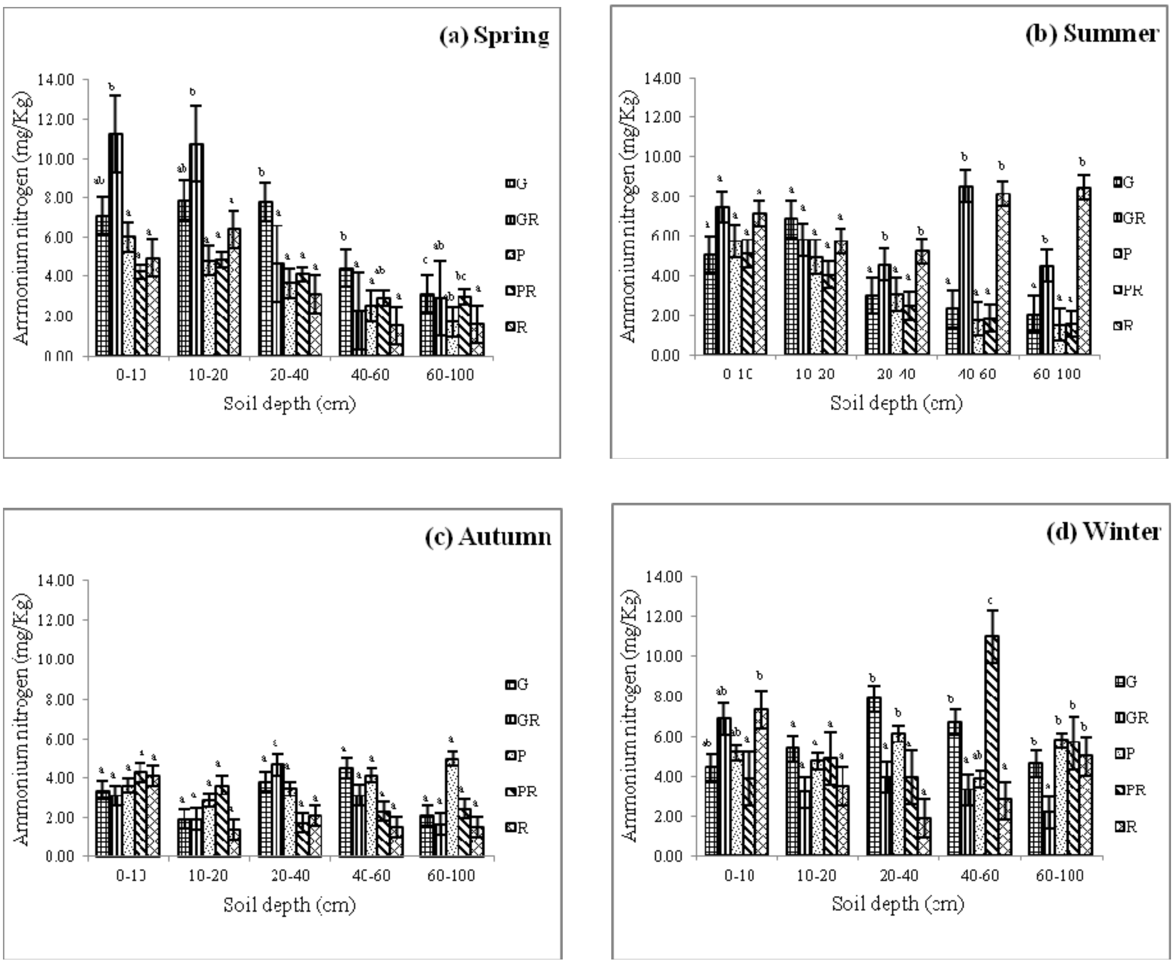


Note: Different letters indicate the significant differences in nitrate nitrogen among the soil depths according to Duncan’s multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 14. Comparison of nitrate nitrogen among the soil depths of different treatments

Soil nitrate nitrogen(NO_3^-) of the same soil layer was different in five managing system (Figure 14). R system had lowest soil bulk in different soil layer of the autumn season, and GR system obtained higher soil bulk in the 0-10cm and 10-20cm soil layer. Soil nitrate nitrogen of 20-40cm, 40-60cm and 60-100cm had high difference among five managing system. The results of ANOVA showed that NO_3^- of different managing system had significant variation in spring, summer and autumn (Table 9-12).

Soil nitrate nitrogen(NO_3^-) also changed with the difference of season, especially topsoil (Figure 14). NO_3^- of the 40-60cm layer in summer was highest in five managing system, and it had a high variation in other three seasons.



Note: Different letters indicate the significant differences in ammonium nitrogen among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 15. Comparison of ammonium nitrogen among the soil depths of different treatments

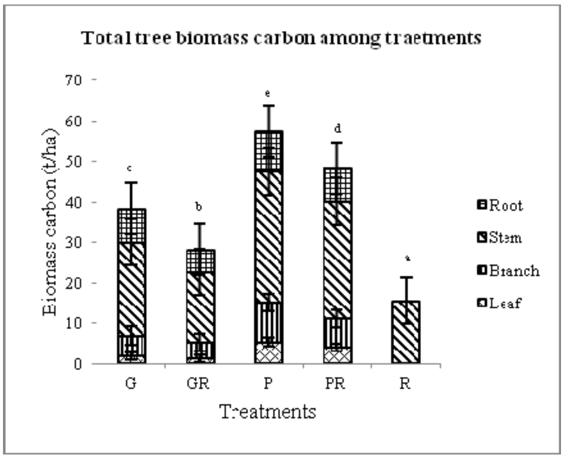
Soil ammonium nitrogen(NH_4^+) changed accordingly with the variation of a managing system, soil depth and season (Figure 15). NH_4^+ decreased with the increasing of soil depth in all managing system of spring but not in other seasons. However, in summer, NH_4^+ obtained the highest value in the soil layer 0-10cm for GR system, and NH_4^+ of topsoil higher than the 10-20cm layer in G, PR and R system. In all seasons, NH_4^+ of 20-40cm, 40-60cm and 60-100cm had a high difference in the same managing system. The results of ANOVA showed that NH_4^+ of different soil depth had significant variation in spring (Table 9-12).Soil ammonium nitrogen(NH_4^+) of the same soil layer was different in five managing system (Figure 14). PR system had lowest NH_4^+ in different soil layer of the summer season, and GR system obtained higher NH_4^+ in the 0-10cm and 10-20cm soil layer. NH_4^+ of 20-40cm, 40-60cm and 60-100cm had high difference among five managing system. The results of ANOVA showed that NH_4^+ of different managing system had significant variation in spring, summer and winter (Table 9-12).

Soil ammonium nitrogen(NH_4^+) also changed with the difference of season, especially topsoil (Figure 15). NH_4^+ of the 0-10cm layer in summer was highest in five managing system, and it had a high variation in other three seasons.

5. Discussion

5.1. Biomass carbon storage

Above-ground biomass is the total amount of oven-dried biological material on the specified soil surface. Among them, plant biomass has the estimated amount 50% carbon of the total above-ground (Drake et al. 2003). Estimation of C storage in different forest stages is essential for assessing the role of forest ecosystems. Our results indicated that P plantations can accumulate large amounts of biomass C, both above and below ground. Biomass C density in all components within treatments was also significant (Table 6). The highest rate of accumulation was observed in P plantation (57.42 t/ha). Generally, C storage of mixed plantations was high, but in this study total tree biomass lowered than the mixed plantations; 28.17 t/ha in GR ~ 38.34 t/ha in G and 48.33 t/ha in PR ~ 57.42 t/ha in P, respectively.



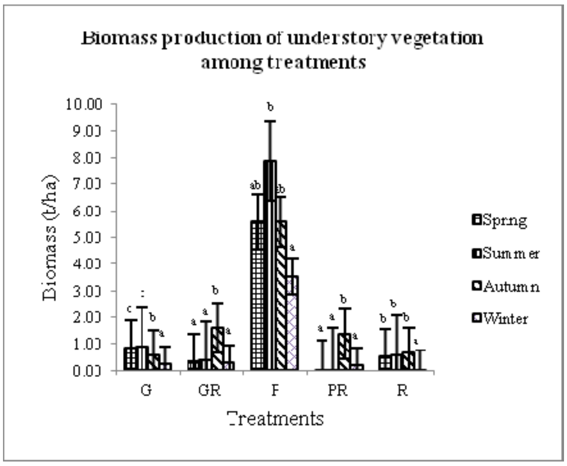
Note: Different letters indicate the significant differences in tree biomass carbon among treatments according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

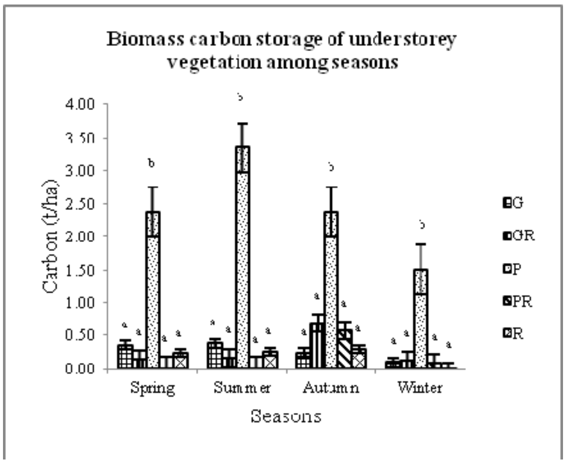
Figure 16. Comparison of total tree biomass carbon among treatments

Tree biomass constituted a major part of the biomass C pool and increased rapidly with plantation age in both the above- and below ground (Li et al. 2011, Chen et al. 2013 & Wang et al. 2013). But the ages between the mixed planted species were quite different in our managing systems. When considering carbon storage, all forest plantations are not equal. Slow growing species with high-density store more carbon per volume than fast growing species with low density in long-term plantations (Costa, 1996). The C in the above- and below-ground biomass of slow growing species such as red oak, black walnut and conifer species, less than comparing with fast growing species such as poplar (Wotherspoon et al. 2014). And also faster growing species had significantly higher ratios of sapwood area to stem area that can store more carbon (Bond-Lamberty et al. 2002). As a result, the fast growing species of pure poplar plantation was highest of biomass production and C storage among our managing systems (Fig 16).

5.2. Understory vegetation carbon storage

The fast-growing species accumulated more carbon in plant biomass, and coniferous forests had a higher live biomass and litter C storage (Gao et al. 2014). In this result, the amounts of the biomass production and carbon storage of understory vegetation among treatments in response to the season were found a significant difference. Among them, the amount of biomass production of understory vegetation was the highest in fast-growing species; P plantation and carbon storage of the understory vegetation was the highest in summer (Fig 17).





Note: Different letters indicate the significant differences in biomass production and biomass carbon storage among treatments and seasons according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 17. Comparison of understory vegetation biomass production and carbon storage

5.3. Soil physical properties

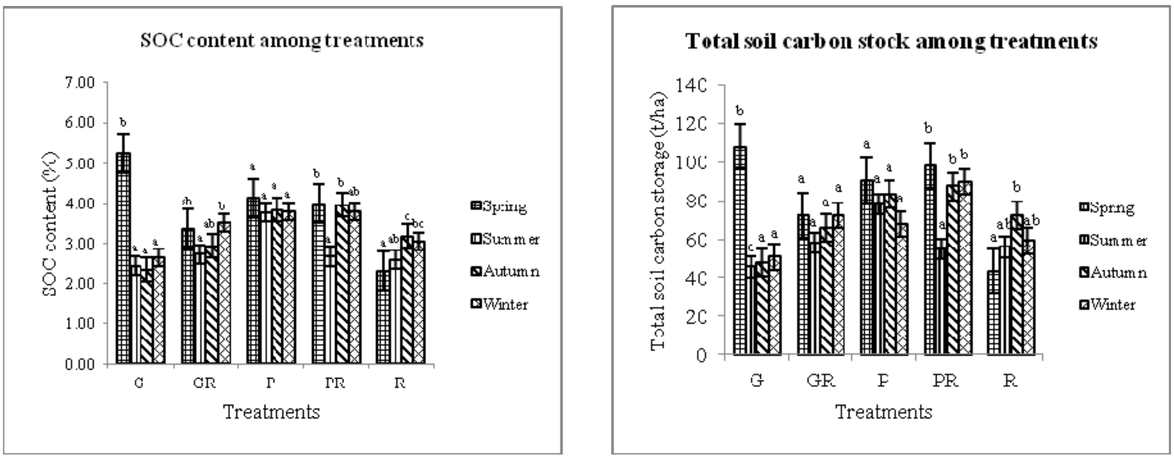
Soil bulk density increases with soil depth and causes compaction that reduces total pore volume and available water-holding capacity (Field et al. 1998). Soil available water capacity can be affected by organic matter and compaction (Field et al. 1998) and also measured site quality in forestry or agriculture indirectly (Tullus et al. 2010). The results indicated that the soil bulk density up to 20 cm of all managing systems was significant. Although soils with a bulk density higher than 1.6 g/cm^3 tend to restrict root growth, our results among managing systems on 1 m depth were increased from 1.17 g/cm^3 to 1.59 g/cm^3. So the soil bulk densities under different treatments don't disturb the tree growth.

Maximum and available water-holding capacity and water content varied by texture and is reduced when compaction occurs. As our results, maximum and available water holding capacity up to 20 cm in spring, summer and winter and but only in autumn for water content were significant. The maximum and available water-holding capacities and water content among treatments within 1 m depth were decreased 43.53%, 35.18% and 0.431% to 17.37%, 10.15% and 0.169% respectively. Soil bulk density increased significantly with increasing soil depth but maximum water holding capacity decreased oppositely (Zhang et al. 2006). When bulk density decreases, benefit to plant growth and rehabilitation by increasing infiltration, percolation, and aeration in the soil. In a mixed plantation, the lower bulk density and the maintenance of SOC that incorporate organic matter into the soil and develop fine roots and will be continued to decrease bulk density (Boley et al. 2009). Although soil bulk density increased with increasing depth in the abandoned land, it was not the same case for all the plantations (Shi et al. 2010). In this result, soil bulk density was increased with soil depth and maximum and available water holding capacities and water content were decreased with soil depth. So, soil bulk density was inversely proportioned with water-holding capacity and water content. Among treatments; G was significantly that was the lowest bulk density and highest maximum and available water-holding capacity and water content.

5.4. Soil chemical properties

According to, Li et al. (2008) noted that species affect on soil pH in many studies and found that pH was significantly higher in soil with higher organic matter content. The pH value of all managing systems was higher than the neutral and range from 7.91 to 8.67 in spring, 7.84 to 8.56 in summer, 7.71 to 8.55 in autumn and 7.50 to 8.25 in winter within 1 m depth. Among them the pH value of P plantation was the highest in spring, summer, autumn and PR plantation was the highest in winter.

Silvicultural management did not reduce total C stocks or influence soil bulk density, but silvicultural activities have induced changes in SOM aggregate (Beldini et al. 2009). The carbon storage and distribution varied among forest types and different plantation ecosystems and was depended on specific traits of trees and understory vegetation. Fonseca et al. 2012 pointed that the 60% of stored carbon has been found 30 cm soil depth and that at lower depths; the soil is less altered and tends more stable. Soil organic carbon in deep soil was more stable than that in shallow soil (Zhang et al. 2015). In this study, SOC content percentage of all treatments up to 40 cm depth was over 60% of total SOC in spring and autumn and over 80% in summer and winter. Among treatments, the SOC content of G is the highest up to 40 cm was 78% in spring, 85% in summer, 77% in autumn and 83% in winter. And also soil carbon storage of GR was the highest up to 40 cm was 59% in spring, G was 68% in summer, GR was 60% in autumn and P was 75% in winter. Mixed species plantation of hybrid poplar and white spruce was greater carbon sequestration than monoculture species plantation of either hybrid poplar or white spruce (Chomel et al. 2014). Above- and belowground carbon storage in mixed stands is higher than the pure pine stand (Fan et al. 2013).



Note: Different letters indicate the significant differences in soil organic carbon among the soil depths according to Duncan's multiple range tests at 5% level of probability. The letters are the rank order from lowest to the highest value (alphabetically). Open bar indicates the standard error.

Figure 18. Comparison of SOC content and soil carbon storage among the soil depths of different treatments

In this study, the percentage of SOC content and soil carbon storage of G was highest in spring but the SOC content percent was the highest in P plantation in other seasons and soil carbon storage of P was highest in summer and soil carbon storage of PR was highest in autumn and winter. And also SOC content of G was higher than GR plantation and P was higher than PR plantation, but R plantation was the lowest. But soil carbon storage of GR is higher than G plantation and PR was higher than P plantation, but R plantation was the lowest.

Soil active organic carbon (SAOC) and microbial organic carbon (MBOC) in soil have high biological activity and play an important role in forest soil ecosystem structure and function. Previous land-use change exerted significant influence on soil active organic carbon content and distribution proportion in the soil profile (Zhang et al. 2015). Water soluble organic carbon (WSOC) is the most mobile and reactive soil carbon source available. It plays an important role in many biogeochemical processes. WSOC was the entire pool of water soluble organic carbon either absorbed on soil or sediment particles or dissolved in interstitial pore water. It is the most important carbon source for soil microorganisms (Sparling et al. 1998; Schnabel et al. 2002; Marschner & Kalbitz, 2003), so both the quantitative and qualitative aspects of WSOC are very important for soil ecosystem studies (Kalbitz et al. 2003; Shamrikova et al. 2006; Baumann et al. 2009). But WSOC accounts for a small portion of the total soil organic carbon content (Ohno et al. 2007; Baumann et al. 2009). The results indicated that the SAOC, MBOC and WSOC for each treatment in response to soil depth were significant differences.

Likewise, both SOC content, soil carbon storage and soil bulk density changed significantly with depth ($p<0.05$ for both). Duncan's multiple range tests showed that maximum and available water holding capacity, water content, and organic matter, SOC content, soil carbon storage, SAOC, WSOC, MBOC, available N, NO_3^- and NH_4^+ decreased with increasing soil depth while soil bulk density and pH increased with increasing soil depth. Soil physical and chemical properties were significant in winter than the others. Trees can influence soil properties due to differences in litter quality, root activity, nutrient uptake and growth (Binkley, 1995; Hagen-Thorn et al. 2004) and give their ability to alter soil properties; especially in soil rehabilitation (Neirynck et al. 2000). The fact that the soil properties were improved with increasing soil depth and demonstrated the progressive changes within managing systems. Tree species and managing systems also affected the storage of soil properties and that depended upon the different ecosystems.

6. Conclusion and recommendations

Plantations can play a significant role in reducing atmospheric carbon dioxide. In this study, we provided not only with an estimation of soil properties but also with the effect of tree biomass and understory vegetations on soil carbon storage for estimating carbon storage under different managing systems. The results of the present study indicated that the establishment of hardwood (e.g., *Ginkgo biloba, Populus tremula and Metasequoia glyptostroboides*) plantations with different managing systems on the Dongtai forest farm resulted in significant improvement in soil properties and carbon storage.

Pure plantation of poplar can rapidly accumulate large quantities of biomass and storage of carbon. Here, tree biomass gradually became the dominant C pool with increasing stand age. The aboveground carbon content was likely to increase according to age and the density of stands. The greater the density of tree stands, the greater the aboveground carbon content (Petsri et al. 2007). Our results suggested that poplar is a fast-growing forest tree with high potential biomass carbon sequestration.

Crop residue and understory vegetations management is another important method of sequestering C in soil and increasing soil carbon storage. As vegetation develops, biomass increases gradually and plants require more soil nutrients, and there is a gradual decrease in the proportion of roots, branches, and leaves, and in the contribution of litter to soil carbon storage. However, mixed pine–hardwood stands can store more carbon than pure pine stand, thus under-planting system should be considered to improve ecosystem carbon sequestration (Fan, 2013). Our results suggested pure plantation of poplar had the highest understory vegetation carbon storage among managing systems.

Soil organic carbon stock in mixed-plantation has high and the absorbing of GHG by the soil of mixed plantation has also been increased. Especially; conifer-broadleaf mixed plantation has higher soil carbon sequestration than monoculture broadleaf plantation in subtropical China (Wang et al. 2013). In mixed-species plantations, the tree species combinations could be improved use of soil resources and potentially sequester more C (Richards, 2007). Older reforested and afforested ecosystems in the tropic can found significant C sequestration (Silver et al. 2004). Our results suggested soil organic carbon content potential for pure plantations of poplar was the highest soil organic carbon content rate and soil carbon storage potential for poplar mixed with dawn redwood plantation was the highest soil carbon storage on 1 m depth.

It is important to consider different carbon storage patterns among the plantations. Species selection can also affect many aspects of ecosystem functions and services to fulfil multiple goals and purposes. Therefore carbon storage potential should not be the only criterion for the ecosystem restoration. In this study, climate conditions and topography for all managing systems were similar. The main reason for the variation in the below-ground carbon storage between managing systems was tree ages and species-specific. Especially, plantation types, tree species and stand age also affected upon the allocation pattern, carbon storage and sequestration of forest plantation (Wei et al. 2013; Chen et al. 2015). According to this study, pure plantation of fast growing species poplar was the suitable for carbon storage within short term plantation. When we assess the soil properties and carbon storage, we need to put not only managing systems but also the tree species, stand age and species density.

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