EFFECT OF CLIMATE CHANGE ON STEM BIOMASS AND CARBON STOCK OF MONGOLIAN SCOTS PINE (*PINUS SYLVESTRIS* VAR. *MONGOLICA*) PLANTATION FORESTS IN HORQIN SANDY LAND, CHINA

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Abstract. Mongolian Scots pine has been used for vegetation restoration and windbreaks in Horqin Sandy land, Northern China, where climate change is the principal factor limiting tree survival and growth. To investigate the effect of annual precipitation and annual temperature variables on stem biomass and carbon stock of Mongolian Scots pine healthy (HP), sub healthy (SHP), stress (STP), and shrink (SRP) plantation. We used climate sensitive allometric model to find out accurate biomass along climatic factors from 1965 to 2019. The result show that, stem biomass and carbon stock of Mongolian Scots pine, HP, SHP, STP and SRP plantation, have strong correlations with annual PP and annual (T_{max}) ($R^2 = 0.88$, $R^2 = 0.84$, $R^2 = 0.82$, $R^2 = 0.61$) and ($R^2 = 0.86$, $R^2 = 0.82$, $R^2 = 0.72$, $R^2 = 0.60$). While, annual average (T_{mini}) and annual (T_{mean}) have a slightly positive correlations with the Mongolian Scots pine, HP and SHP, plantation ($R^2 = 0.73$, $R^2 = 0.70$) and ($R^2 = 0.76$, $R^2 = 0.71$). However, negative correlations ($R^2 = 0.49$, $R^2 = 0.29$) and ($R^2 = 0.40$, $R^2 = 0.39$) were found with STP, and SRP, plantation. Mongolian Scots pine, afforestation on reclamation sites brings important environmental and production benefits. Mongolian Scots pine has a strong adaptive nature with climate change and hence can survive under stress conditions of Horqin sandy land China.

Keywords: *Pinus sylvestris var. mongolica, stem biomass, carbon stock, global warming, afforestation*

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Introduction

It is universally admitted that climate change is influencing forest ecosystems. There is enough evidence that indicating the potential downfall in amazon rainforest, related to climate change (Pecl et al., 2017; Zhu et al., 2019; Ayanlade et al., 2020). Due to water deficiency, barren soil, and scattered vegetation, desert ecosystems, may be particularly exposed to climate change (Seddon et al., 2016; Zhu et al., 2019; Jordaan et al., 2020). It has been considered that soil degradation caused by desertification influences one-quarter of the world's land cover, including one fifth of the world's community, mostly living in emerging countries (D'Odorico et al., 2013; Turan et al., 2019). This amount will extensively increase in the coming decades, given the forecasted rise in aridity linked to climate change (Huang et al., 2016, 2017). Precise understanding the influence of climate change on desert ecosystems, therefore, its essential and integral to their stability (Vogt et al., 2011). Furthermore, in past decades, climatic changes have deeply affected the composition and of territorial ecosystems, driving to uncertainties concerning ecological rehabilitation in desert areas (Zhou et al., 2015). Assumed these climatic changes, studying trees dynamics and its relationship with climatic factors is necessary for understanding how the changing climate alters the dry ecosystems (Wang et al., 2013).

As an active component of ecosystems, forests links the soil and atmosphere through energy and mass transport; thus, it is a sensitive indicator of environmental change (Piao et al., 2006). Monitoring Stem biomass and carbon stock dynamics and analysing their responses to climatic variations are popular approaches to studying global climate change (Virtanen et al., 2010; Svenning and Sandel, 2013; Yin et al., 2016). Mongolian Scots pine, growth can be endorsed by increased precipitation and temperature in northern and upper areas where production is cold-limited (Kullman and Kjällgren, 2006; Briffa et al., 2008). However, evidence indicates that cold-constrained sites also influence Mongolian Scots pine growth due to aggravated soil moisture deficit, linked to increasing demand for evapotranspiration during the growing season (Lloyd and Bunn, 2007; Düthorn et al., 2016). The influence of minimum temperature and mean temperature brings uncertainty to tree growth and vigor throughout the range, specifically in cold-dry climates (Matías and Jump, 2012). Moreover, other dry environments, particularly warmer areas of Mediterranean, where Mongolian Scots pine also exposed to winter and responsive atmosphere (Camarero et al., 2015; Marqués et al., 2018). In this concern, the comparison of low temperature and warm atmosphere has a simultaneous effect on Mongolian Scots pine growth, which is of particular interest to predict the climate change influences on conifer species (Babst et al., 2017; De Andres et al., 2017).

Mongolian Scots pine was introduced for afforestation in the 1950s to Horqin Sandy Land, China. Now it has become the most commonly used tree species for creating shelterbelt plantations, condense to soil water conservation, and increase sand fixation in Horqin Sandy land China (Zhu et al., 2005). Since the early 1990s, Mongolian Scots pine plantations began to decline due to dieback, the absence of natural regeneration, low growth rates, and mortality (Shuren, 2001; Zheng et al., 2012). There is a remarkable expansion in desertification across Mongolia due to climate warming at a global scale, and it has potential influence on plantations in current years (Sternberg, 2008; Gerelbaatar and Baatarbileg, 2011). Because of this decline, a large number of studies have been conducted from many perspectives, including water use strategy, decreasing groundwater, hydraulic architecture, and differences in plant nutrients and soil microbes among origin regions (Song et al., 2016; Liu et al., 2018; Zhang et al., 2019b). However, its impact on the carbon sink is minimal. Basic research has been conducted to evaluate the response of potential biomass changes and carbon storage *Pinus sylvestris* var. *mongolica* plantations to climate change.

In this paper, we studied Mongolian Scots pine plantations forests stem biomass and carbon stock along with the climatic factors in Horqin Sandy Land, China. Our main objective of this study was to find out a correlations of climatic variables, including annual precipitation and annual temperature variables, with the stem biomass and carbon stock of Mongolian Scots pine plantations, to investigate tree growth survival in drought conditions. It is anticipated that the results of this study might be helpful for the management of forest plantations concerning the growth conditions of Mongolian Scots pine.

Materials and methods

Study area

The present study was conducted at the Liaoning Province Sand-Fixation and Afforestation Research Institute, which is located above sea level (42°420 N, 122°290 E, 220.67 m) in Horqin sandy land, Northeast China (*Fig. 1*). The Horqin Sandy Land is the major sandy land of the country and an important section of the Three North Shelterbelt regions. The whole region is characterized by a moderate, semi-humid monsoon climate, with annual average temperature and precipitation in this region from (1965-2019) were 7.7 °C and 500 mm, respectively, with nearly 67.0% of the precipitation occurring from June to August and the annual frost-free period is 150 to 160 days. The geomorphology is characterized by staggered distributions between oval or round sand dunes and low-lying land caused by wind erosion. The primary soil type is Aeolian sandy soil, accounting for 89.4% of soil, and other soil types include meadow soil, peat soil, and paddy soil.

Mongolian Scots pine is naturally distributed in the mountainous region of northeast China (Zhu et al., 2006). Because of its strong drought tolerance and fast growth, this species was first introduced successfully to Horqin sandy land in the 1950s, under the project of Three-North Shelterbelt regions during the past few decades (Zhu et al., 2016). It has become the main tree species widely used for afforestation in water-limited sandy lands of China. There are a large number of Mongolian Scots pine plantation stands of different ages and densities. Other woody plants in this region include *Pinus tabuliformis Carr. Populus L. and Ulmus pumila L*. The main understory herbaceous plants have *Digitaria sanguinalis (L.) Scop. Setaria viridis (L.) Beauv, Chloris virgate Sw, Cleistogenes squarrosa (Trin.) Keng, Eragrostis pilosa (L.) Beauv, Geranium wilfordii Maxim, Elymus dahuricus Turcz, Euphorbia pekinensis Rupr, Portulaca oleracea L., and Axyris amaranthoides L.*

Field data collection

A field survey was conducted in 2019 to collect data from the study area Zhanggutai region. Trees of different growth states of Mongolian Scots pine, healthy, sub-healthy, stress, and shrink plantation were chosen from 5 location as a target tree to investigate the Stem biomass and carbon stock (*Fig. 2*). Recorded the location information such as geographic coordinates and altitude (*Table 1*), as well as the basic information of individual trees such as diameter at breast height, tree height. Within each plot, tree diameter at the breast (DBH) of each tree measured by caliper, while tree height was measured by concern indicator (NIKON 550S, TOKYO, JAPAN).

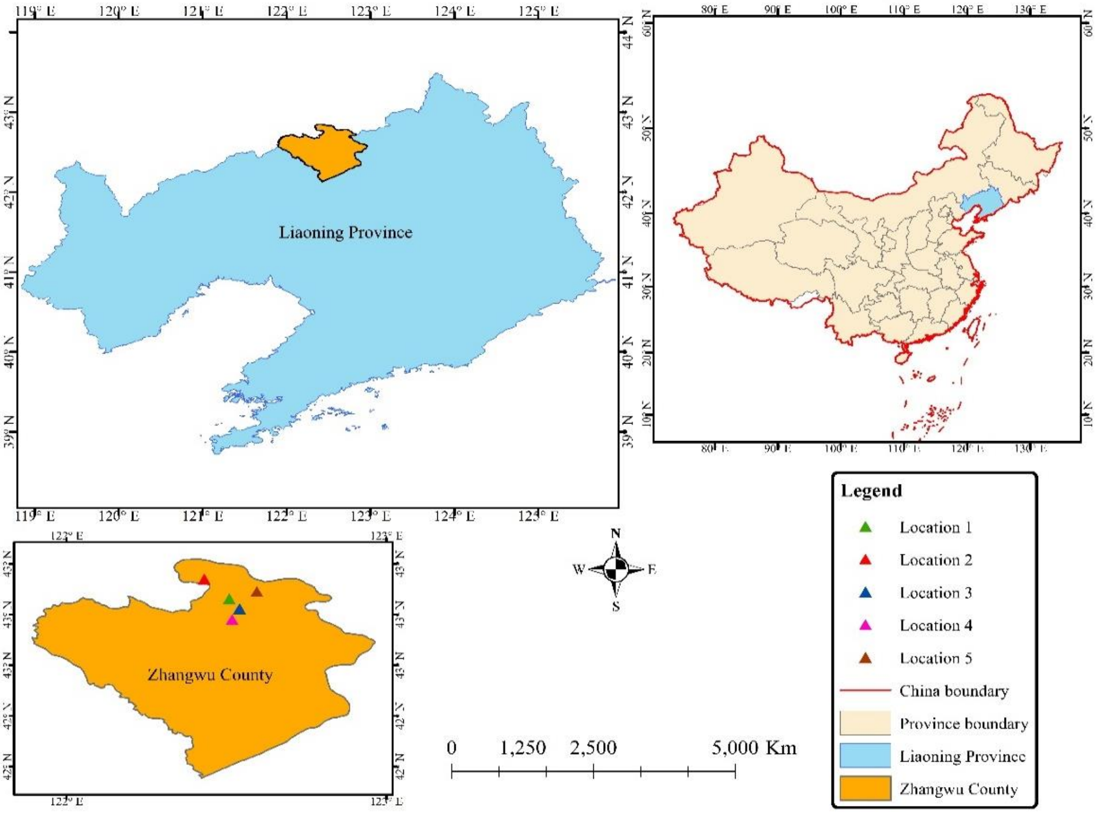

Figure 1. *Sketch sites map of geographic division of Horqin Sandy land, Liaoning Province, Northern China*

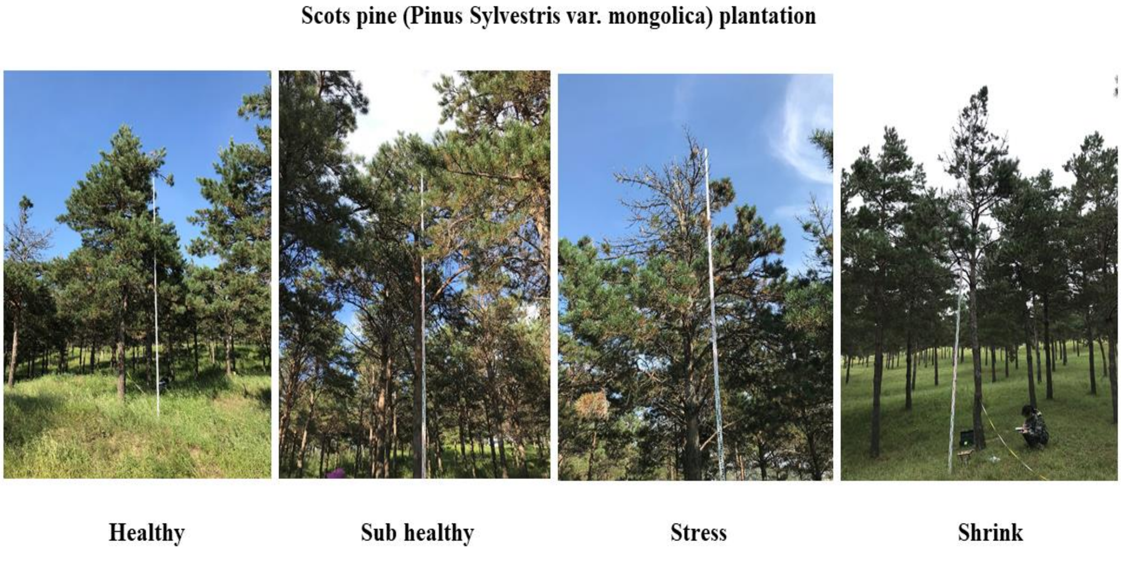

Figure 2. *Mongolian Scots pine (Pinus sylvestris var. mongolica) plantation health condition*

Table 1. *Description of study site of Pinus sylvestris var. mongolica, health condition, and samples*

Mongolian *Scots* pine	Health *status*	Longitude	Latitude	Altitude (m)	Number of sampled trees
1	Healthy	122°25′49″	42°47′3″	252	150
2	Sub healthy	122°30′4″	42°43′7″	90	140
3	Stress	122°32′57″	42°40′57″	199	141
4	Shrink	122°34′31″	42°41′28″	86	146
Total					577

Climatic data collection

The climatic data, such as annual maximum temperature, annual minimum temperature, annual mean temperature, and annual precipitation, were collected from 1965 to 2019 (*Fig. 3*). KNMI Climate Explorer (htttps://climexp.knmi.nl) was used to download the (0.5°) grid data of these parameters. These selected climate stations were consistently assigned in the northeastern region of Inner Mongolia, China. The global positioning system (GPS) was used to download the Climatic data of each sample plot from its coordinate and to extract geographical data of each sample plot. We used regression analysis between interpolated and measured temperature variables and precipitation to calculate the accuracy of interpolated values. Climatic factors such as Temperature variables were divided into three main seasons, such as summer (July, August, September, October), winter (November, December, January, and February), and mid-season (Match, April, May, and June).

Stem biomass

Researchers have developed several allometric equations to estimate biomass of diverse tree species using many variables as predictors or independent variables. For estimation of tree biomass, a standard variable such as DBH, total height, density, volume, basal area, and crown radius are mainly used (Chave et al., 2005; Mandal et al., 2013; Goodman et al., 2014). In forest ecological system the biomass is an important part. Quantifying accurate tree biomass is necessary to investigate the carbon storage and the effect of climatic factors such as precipitation and temperature variables (Clark et al., 2001; Wang et al., 2017). Although measuring the actual weight of tree constituents such as stem, root, foliage and branches the suitable method, however, it is time-consuming, costly and destructive. Therefore, to estimate tree biomass the stem biomass model is supposed to be the finest method (Bi et al., 2004; Dong et al., 2015). Recommended components such as height of the tree (H) and diameter at the breast height should be used to measure stem biomass (Chave et al., 2006). Minimum standard error (SRR) is used for a tree model and is accounted realistic if it yields evaluate on it, throughout the range of data the minimum sum if the square of the residual error (SSE) does not give negative estimates and does not exhibit a reduction in biomass with an escalation in height or diameter. Whereas minimum standard error (SEE) is used for a tree model and considered reasonable if it yields estimates on it, the minimum sum of the square of the residual error (SSE) during the range of data, does not give negative estimate (Ali et al., 2016). The following allometric equation was used, which was developed by (Cheng and Li, 1989):

Biomass Equation Ws = 0.0134(D2 H) 1.02 (Eq.1)

The coefficient of determination of (R^2) is 0.0134. Where (Ws) indicated stem biomass, (D) indicated tree diameter at breast height, and (H) indicated tree height, respectively. To measure, the total stem biomass per plot was summed for all plots to average carbon stock and biomass of the separate plot, subsequently converted to tons per hectare (ton/ha). To convert the value to its carbon equivalent biomass fraction analysis was carried out. Carbon stock was measured as the corresponding biomass of the individual tree and product of the carbon sink.

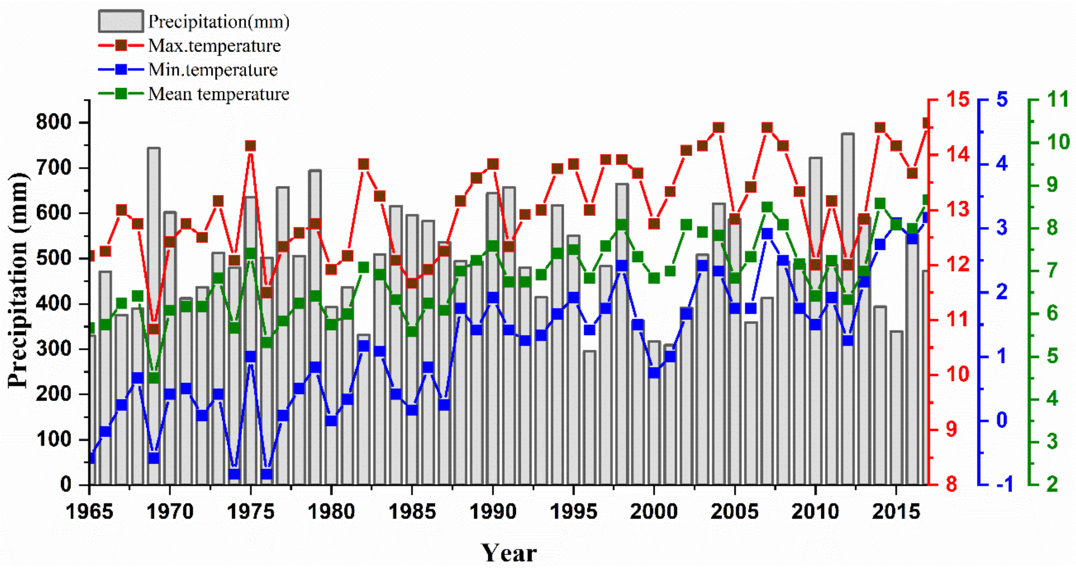

***Figure 3.** Yearly climate diagram for annual precipitation, annual maximum temperature, annual minimum temperature, and annual mean temperature from 1965 to 2019 from the sampling plots for Mongolian Scots pine (Pinus sylvestris var. mongolica), in Horqin Sandy Land, China*

Data analyses

The relative change rate of biomass was used as the dependent variable, and climatic variables were used as the independent variables for stepwise regression analysis. Correlation’s analysis was used to determine the association among two variables. Climatic factors such as annual temperature and annual precipitation affect the relative change rate of biomass were achieved with the following regression equation:

$$\boldsymbol{B = \beta_0 + \beta_i P_i} \tag{Eq.2}$$

where b is the relative change rate of biomass, β_0 is a constant, and β_i is the coefficient estimates of effecting factor i.

Estimated biomass was as

$$\boldsymbol{B = \frac{\beta_i\ P_j}{X_i} X_i + B_j(1 + \beta_0 - \beta_i)} \tag{Eq.3}$$

where B_j is the measured value of biomass in adjacent land, the positive and negative effects of biomass variation with climatic factors have the same positive and negative effects of biomass as their corresponding factors of the forest, but the coefficient estimates are different. To detect the effect on biomass and stand age with climatic factors such precipitation and temperature changes, Stepwise regression analysis was carried out in which the stem biomass was taken as dependent variables while climatic factors were independent variables. To uncover the relation between variables and to detect the statistical differences among climatic factors and biomass, such as precipitation and temperature (Origin 2018) was used to detect these differences. The level of significance ($R^2 = 0.05$) and level of probability ($P \leq 0.05$) were evaluated in the analysis of variance (ANOVA). To check the variable relationship accuracy, we used linear regression analysis. All statistical analyses were done with Origin 2018 on Windows 10.

Results

Mongolian Scots pine, healthy plantation, amount of stem biomass, and carbon stock with climatic factors

Climatic factors significantly influence stem biomass and carbon stock of Mongolian Scots pine healthy plantation. The average stem biomass 46.5 ± 17.3 (ton/ha), variation from minimum to maximum 20 ± 80 (ton/ha) was measured. Simultaneously, the total average stem biomass of 164 (ton/ha) was recorded. Carbon stock was measured at 23.2 ± 8.6 to 10 ± 40 (ton/ha) with, total average carbon stock of 82 (ton/ha) in the study area. The total average precipitation of 382 (mm) was recorded with the range of 479 ± 109.1 (mm) along, variation from minimum to maximum 280 ± 660 (mm). Maximum temperature range was 11.9 ± 3.3 to 7 ± 18 (°C) with a total average of 10 (°C), While minimum temperature was noted at the range of -2.7 ± 1.3 (°C) to -5 ± 0 (°C), total average -2 (°C) and 6.7 ± 1.7 to 4 ± 10 (°C) total average mean temperature -2 (°C) were found. The maximum and minimum values of stem biomass and carbon stock of healthy plantation beside with climatic factors are described in *Table 2*.

Table 2. *Mean and SD of stem biomass, carbon stock, annual precipitation (PPT), and annual (T_a) temperature variables of Mongolian Scots pine healthy, plantation in Horqin sandy land, China*

Mongolian Scots pine	Statistical variables	Biomass (ton/ha)	Carbon stock (ton/ha)	PPT (mm)	Max Tm (°C)	Mini Tm (°C)	Mean Tm (°C)
Healthy	Mean	46.5	23.2	479	11.9	-2.7	6.7
	SD	17.3	8.6	109.1	3.3	1.3	1.7
	Minimum	20	10	280	7	-5	4
	Maximum	80	40	660	18	0	10
	Total	164 ton/ha	82 ton/ha	382 mm	10 °C	-2 °C	6 °C

Correlations of climatic factors with stem biomass and temperature variables with Scot pine, healthy, sub healthy, stress, and shrink plantation

Mongolian Scots pine healthy (HP), sub healthy (SHP), stress (STP) and shrink (SRP) plantation stem biomass correlations with precipitation, temperature variables 1965-2019. To determine the correlations with climatic factors showed the strongest coefficient correlations ($p < 0.05$). Stem biomass response of Mongolian Scots pine along annual precipitation (PP), was as follows: Annual (PP) has the strongest correlations with (HP), plantation ($R^2 = 0.88$), (SHP), plantation ($R^2 = 0.84$), and (STP), plantation ($R^2 = 0.84$). while, slightly positive correlations were found with (SRP), plantation ($R^2 = 0.61$), in the study area of Horqin sandy land, as shown in *Figure 4a-d*. (HP), plantations and (SHP), plantations a positive correlations with annual maximum temperature ($R^2 = 0.88$), ($R^2 = 0.82$). While, slightly positive correlated ($R^2 = 0.72$) with (STP), plantation. However, significant correlations ($R^2 = 0.60$) was found with (SRP), plantation in Horqin sandy land China, as shown in *Figure 5a-d*.

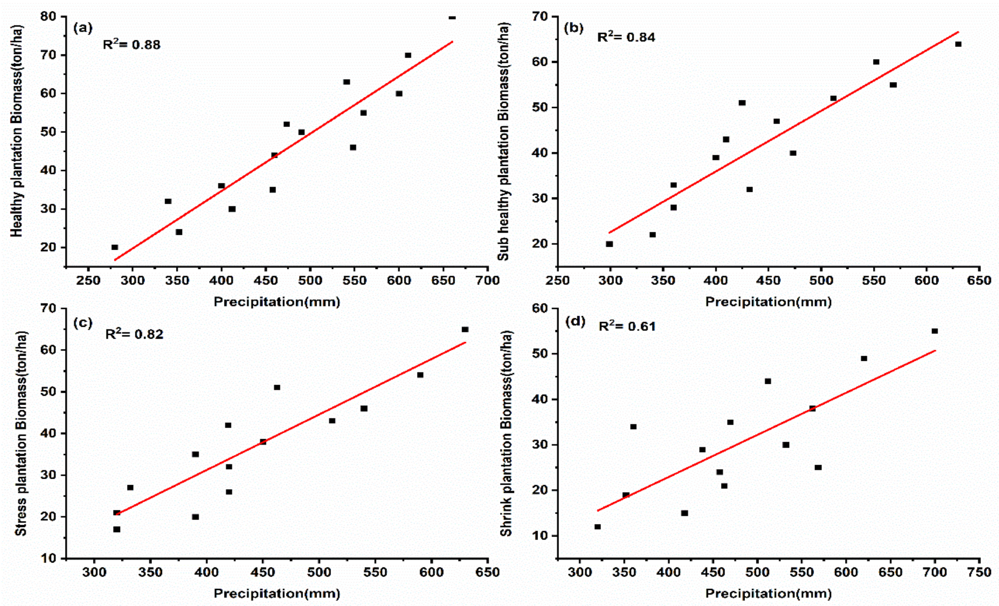

Figure 4. *Association between Pinus Sylvestris var. mongolica, stem biomass along with annual precipitation from 1965 to 2019: (a) healthy; (b) sub healthy; (c) stress; (d) shrink plantation*

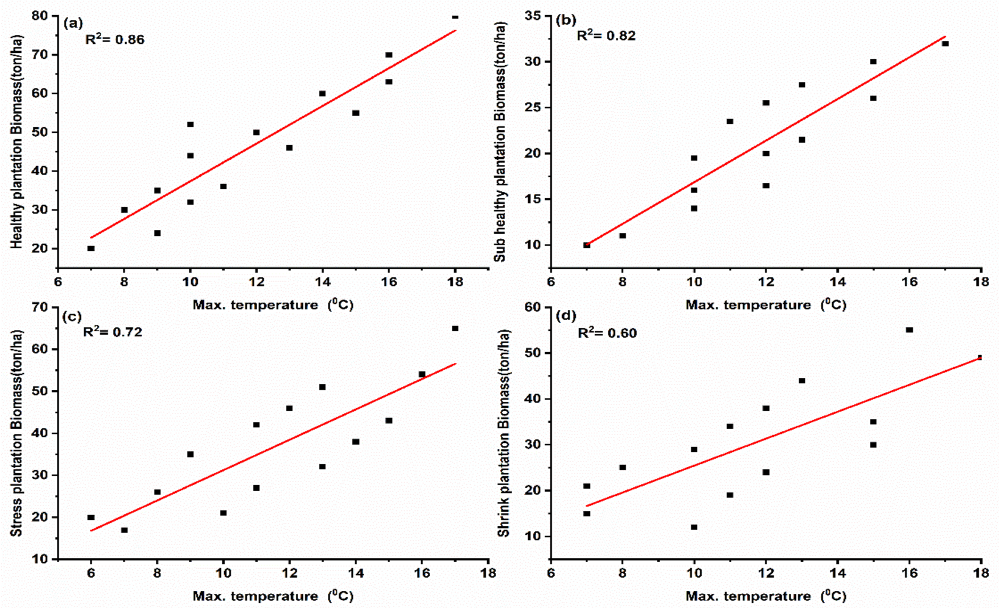

Figure 5. *Relationship between Pinus sylvestris var. mongolica, stem biomass along with annual maximum temperature from 1965 to 2019: (a) healthy; (b) sub healthy; (c) stress; (d) shrink plantation*

Although, Mongolian Scots pine correlations result with annual minimum temperature is not the same. Stem biomass of (HP), and (SHP), plantation response positively correlated ($R^2 = 0.73$), ($R^2 = 0.70$), while negative correlations were observed with (STP), and (SRP), plantation with annual minimum temperatures ($R^2 = 0.49$) 5, ($R^2 = 0.29$), respectively (*Fig. 6a-d*).

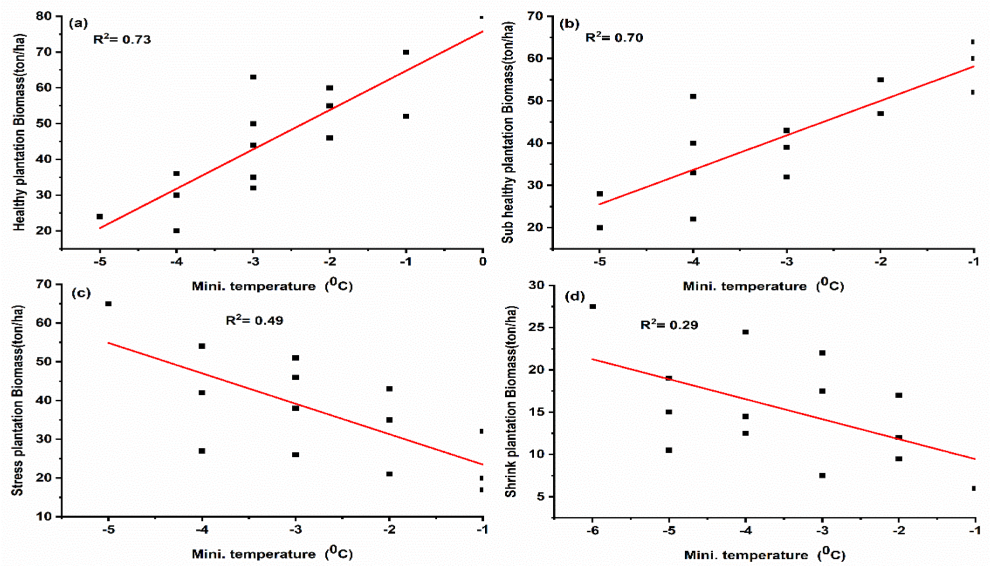

Figure 6. *Relationship between Pinus Sylvestris var. mongolica, stem biomass along with annual minimum temperature from 1965 to 2019: (a) healthy; (b) sub healthy; (c) stress; (d) shrink plantation*

In addition to the correlations with an annual mean temperature of Mongolian Scots pine, (HP), (SHP), (STP), and (SRP), plantation were different (*Fig. 7a-d*). The annual mean temperature was positively correlated ($R^2 = 0.76$) with a (HP) plantation (*Fig. 7a*), while significant positive correlations ($R^2 = 0.71$) with a (SHP), plantation (*Fig. 7b*). However, negative correlations were found for stem biomass of Mongolian Scots pine (STP), and (SRP), plantation ($R^2 = 0.40$) ($R^2 = 0.39$) with annual mean temperature in Horqin sandy land China (*Fig. 7c, d*).

Pinus sylvestris var. mongolica, sub healthy plantation cumulative stem biomass, carbon stock with climatic parameters

Stem biomass and carbon stock of Pinus mongolica sub healthy plantation with climatic parameters presented enormous differences in their carbon stock and biomass. The average stem biomass is 41.9 ± 13.7 (tons/ha), variation started of sample from minimum to maximum 20.0 ± 64.0 (ton/ha), although the average 140 (ton/ha) of stem biomass was calculated. Carbon stock was measured at the range of 20 ± 6.9 to 10.0 ± 32.0 (ton/ha) with a total average of 70 (ton/ha) carbon stock in the study area. The total average precipitation of 367 (mm) was recorded with the range of 444.2 ± 94.9 (mm) along with variation from minimum to maximum 299.0 ± 630.0 (mm). Maximum temperature range 11.8 ± 2.8 to 7.0 ± 17.0 (°C) with a 10 (°C) of the total average temperature. Minimum temperature, noted at the range of -3.0 ± 1.4 (°C) to -5.0 ± -1.0 (°C), with total average minimum temperature -2 (°C) respectively. Mean temperature varies from 5.3 ± 2.1 (°C) to 2.0 ± 9.0 (°C), with total average of 5 (°C). The maximum and minimum values of stem biomass and carbon stock of sub-healthy plantation were found along with climatic variables in study area, which are presented in *Table 3*.

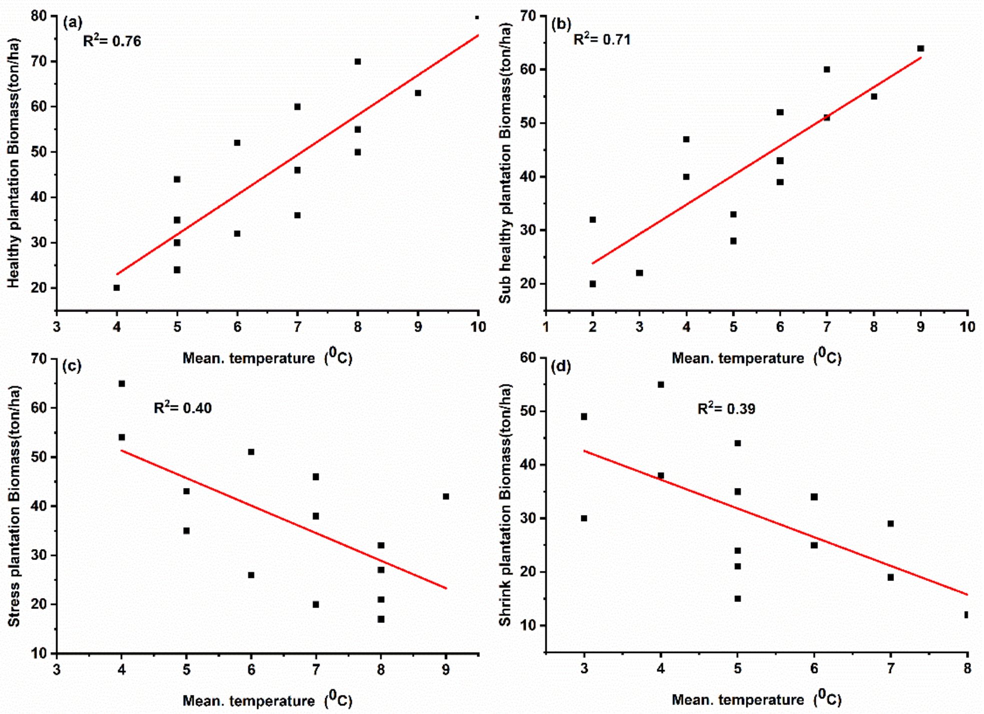

Figure 7. *Relationship between Pinus Sylvestris var. mongolica, stem biomass along with annual mean temperature from 1965 to 2019: (a) healthy; (b) sub healthy; (c) stress; (d) shrink plantation*

Table 3. *Mean (M) and standard deviation (SD) of stem biomass, carbon stock, annual precipitation (PP), and annual temperature (T_a) variables of Mongolian Scots pine sub healthy plantation in of Horqin Sandy Land, China*

Mongolian Scots pine	**Statistical variables**	**Biomass (ton/ha)**	**Carbon stock (ton/ha)**	**PP (mm)**	**Max Tm (°C)**	**Mini Tm (°C)**	**Mean Tm (°C)**
Sub healthy	Mean	41.9	20.9	444.2	11.8	-3	5.3
	SD	13.7	6.9	94.9	2.8	1.4	2.1
	Minimum	20	10	299	7	-5	2
	Maximum	64	32	630	17	-1	9
	Total	140 ton/ha	70 ton/ha	367 mm	10 °C	-2 °C	5 °C

Pinus sylvestris var. mongolica, stem biomass and carbon stock with stand age

It is comparatively easy to predict stand stem wood biomass with stand age. This relationship is quite similar to that between stem wood biomass, carbon stock, and stand volume. Most investigations indicate that stem biomass increases in with stand increment (Ilvesniemi and Liu, 2001; Jagodzinski and Kalucka, 2008), besides that, some additional studies exhibited a variation even later; for example, “the second

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maximum" can be found at a stand age of 40 to 50 years (Makarenko, 1985). Also, some investigations show that stem biomass increases slowly up to maturity (Mikšys et al., 2007; Burrascano et al., 2013). Carbon capture by biomass growth and the duration of carbon in biomass resulted in carbon stocks of forests (Körner, 2017) described that "rather than growth rate tree endurance controls the carbon capital of forests." He further elaborated, that the size of an ecosystem's carbon pool and its carbon turnover is "normally not correlated" and hypothesizes that a system's carbon residence time must be prolonged to reserve carbon fluxes from the atmosphere to the forest biomes. The traditional perspective of sustainable forest management fails when carbon residence in a forest ecosystem is considered, which focuses on the balance of increment and fellings. Even when the forest ecosystem perspective is widened to a forest sector perspective, the forest carbon loss induced by logging activities in tropical forests can often not be compensated by accounting for the carbon pool in harvested wood products and the carbon substitution effects by timber utilization (Butarbutar et al., 2016). A previous study (Brienen et al., 2015; Huang et al., 2021) described a declining trend of carbon accumulation during the past decade for the Mongolian Scots pine plantation. Our result also elaborated that stem biomass and carbon stock increase in Pinus sylvestris healthy, sub-healthy plantation with age. At the same time, the sudden decline was observed in stress and shrink plantation in Horqin sandy land in *Figures 8* and *9a-d*. In addition, the decline is a consequence of the limitation of carbon resistance time due to increased mortality and growth rates that level off. Although carbon stock dynamics occur in significantly huge areas, they can be recognized as individual tree collectives' dynamics. High biomass carbon stocks reduce shifts in size distributions towards trees with larger dimensions necessary (Körner, 2006, 2017). Stand level dynamics determine by large trees (Newbery and Ridsdale, 2016), they play an essential role in minor-scale carbon storage and accumulation. Declines in carbon accumulation can be limited in time.

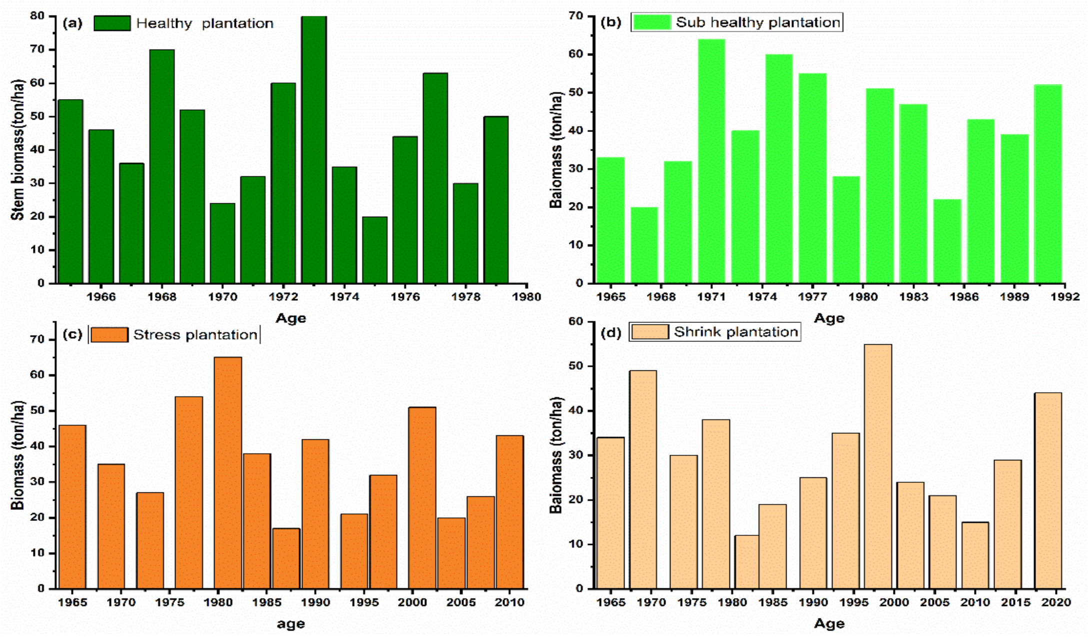

Figure 8. *Accumulation of Pinus Sylvestris var. mongolica, stem biomass of (a) healthy (b) sub healthy (c) stress and shrink plantation at different age from 13, 26, 39, and 54-year-old stands in Horqin Sandy Land China*

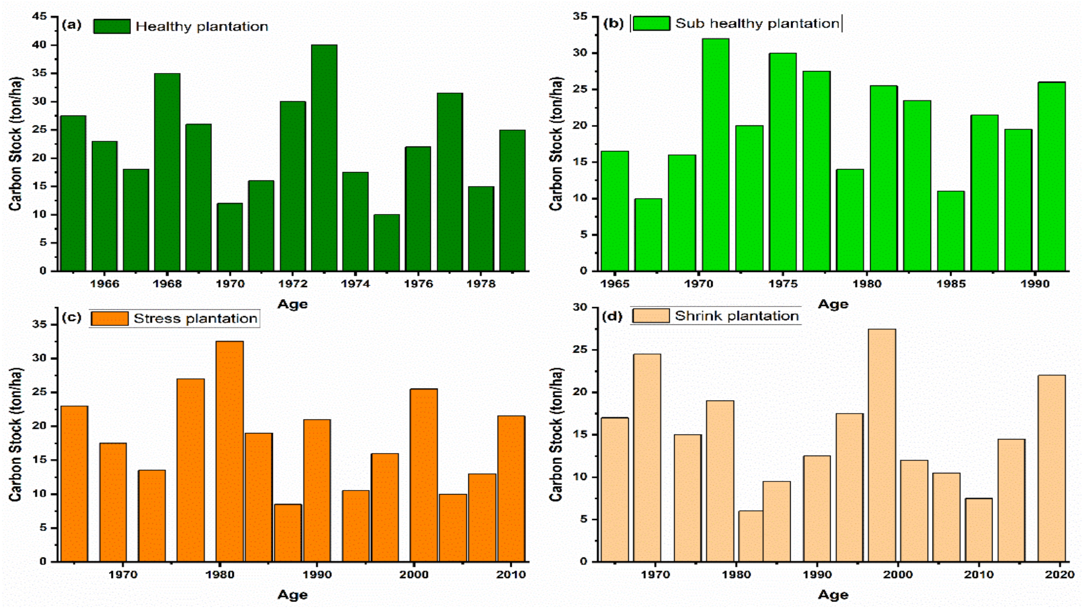

Figure 9. *Accumulation of Pinus Sylvestris var. mongolica, carbon stock of (a) healthy (b) sub healthy (c) stress and shrink plantation at different age from 13, 26, 39, and 54-year-old stands in Horqin Sandy Land China*

Mongolian Scots pine stress plantation, amount of stem biomass, and carbon stock with climatic variables

With climate factors, Mongolian Scots pine stress plantation, stem biomass and carbon stock displayed a vast difference. The average stem biomass 36.9 ± 14.2 (ton/ha), through minimum to maximum 17.0 ± 65.0 (ton/ha) was recorded. While the total average 133 (ton/ha) stem biomass was recorded. Carbon stock ranged from 18.5 ± 7.1 to 8.5 ± 32.5 (ton/ha) with, total average of 67 (ton/ha) carbon stock was found. However, Total annual precipitation 372 (mm) was recorded with the range of 442.5 ± 96.5 (mm), with a minimum to maximum 320.0 ± 630.0 (mm). Furthermore, the maximum temperature ranged from 11.6 ± 3.3 to 6.0 ± 17.0 (°C) with a total average temperature of 9 (°C). Minimum temperature was noted from -2.7 ± 1.3 (°C) to -5.0 ± -1.0 (°C), with total average minimum temperature of -2 (°C). On the other hand, Mean temperature varied from 6.3 ± 1.8 to 4.0 ± 9.0 (°C) with a total average mean temperature of 5 (°C). We found that stress plantation statistics values of stem biomass and carbon stock and climatic factors are described in *Table 4*.

Table 4. *Mean (M) and standard deviation (SD) of stem biomass, carbon stock, annual precipitation (PP), and annual temperature (T_a) variables of Mongolian Scots pine stress plantation in Horqin Sandy Land, China*

Mongolian Scots pine	**Statistical variables**	**Biomass (ton/ha)**	**Carbon stock (ton/ha)**	**PP (mm)**	**Max Tm (°C)**	**Mini Tm (°C)**	**Mean Tm (°C)**
Stress	Mean	36.9	18.5	442.5	11.6	-2.7	6.3
	SD	14.2	7.1	96.5	3.3	1.3	1.8
	Minimum	17	8.5	320	6	-5	4
	Maximum	65	32.5	630	17	-1	9
	Total	133 ton/ha	67 ton/ha	372 mm	9 °C	-2 °C	5 °C

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Mongolian Scots pine Shrink plantation, amount of carbon stock and stem biomass, with climatic variables

Carbon stock and stem biomass of Mongolian Scots pine, shrink plantation with climate parameters presented a significant difference in their carbon stock and biomass. In the current study, we measured 30.7 ± 12.7 (tons/ha) average stem biomass, variation started from minimum to maximum of 12 ± 55 (ton/ha), even if the filled average of stem biomass 110 (ton/ha) were documented. Whereas, Carbon stock was verified at 15.4 ± 6.3 to 6 ± 27.5 (ton/ha) with, total average carbon stock of 55 (ton/ha). Additionally, annual precipitation 403 (mm) was recorded with the range of 483.7 ± 107.1 (mm), alongside a minimum to maximum 320 ± 700 (mm). Furthermore, maximum temperature range from 12.3 ± 3.4 to 8 ± 18 (°C) with a total average temperature of 10 (^{0}C) and minimum temperature, noted at the range of 10 ± 1.5 (°C) to -6 ± -1 (°C), with total average minimum temperature -2 (°C) respectively. However, mean temperature varies from 5.2 ± 1.5 (°C) to 3 ± 8 (°C), with total average of 4 (°C). Statistical values of carbon stock and stem biomass of *Pinus sylvestris* var. *mongolica*, shrink plantation with climatic factors are presented in *Table 5*.

Table 5. *Mean (M) and standard deviation (SD) of stem biomass, carbon stock, annual precipitation (PP), and annual temperature (T_a) variables of Mongolian Scots pine shrink plantation in Horqin Sandy Land, China*

Mongolian Scots pine	**Statistical variables**	**Biomass (ton/ha)**	**Carbon stock (ton/ha)**	**PP (mm)**	**Max Tm (°C)**	**Mini Tm (°C)**	**Mean Tm (°C)**
Shrink	Mean	30.7	15.4	483.7	12.3	-3.5	5.2
	SD	12.7	6.3	107.1	3.4	1.5	1.5
	Minimum	12	6	320	8	-6	3
	Maximum	55	27.5	700	18	-1	8
	Total	110 ton/ha	55 ton/ha	403 mm	10 °C	-2 °C	4 °C

Discussion

Mongolian Scots pine is often used in the afforestation of sandy land and reclamation areas (Kuznetsova et al., 2010; Pietrzykowski and Socha, 2011; Jagodziński et al., 2019). Mongolian Scots pine is an extremely drought-tolerant species and drought stress is thought to be the main climate limitation for its radial growth in semi-arid or arid regions, such as in the Mongolia Plateaus and north eastern Horqin sandy land China (Liu et al., 2009; Pederson et al., 2013; Bao et al., 2015). Previous studies suggest that the radial growth of Mongolian Scots pine is sensitive to precipitation, temperature (Bao et al., 2015). In these areas, the radial growth of Mongolian Scots pine usually has a typical climatic response pattern with a positive tree growth response to increasing precipitation and a negative response to increasing temperature (Davi et al., 2006; Martínez-Sancho et al., 2018). This typical climate factors response pattern is usually found in other drought or wetland tree ring reconstructions (Liu et al., 2017).

Our results depicted the positive correlations with annual maximum temperature and annual precipitation with stem biomass of Mongolian Scots pine (*Figs. 4* and *5*). Our results are consistent with the previous investigations (Qian and Qin, 2006). Recognizing the beneficial role of precipitation and temperature in tree growth. The carbon storage and stem biomass concentration was not comparable to climatic factors in Mongoina Scots pine, healthy (HP), sub healthy (SHP), stress (STP), and shrink (SRP), plantation. Ultimately caused inconsistency in the development of the tree health condition. The highest positive effect on tree growth was observed in terms of annual precipitation and annual maximum temperature. Similarly, (Vacek et al., 2017) showed that precipitation and temperature are the essential variables for pine tree growth during the growing season. Our study confirmed that annual precipitation and the maximum temperature had the highest effect on stem biomass of Mongolian Scots pine plantation. Such findings were also confirmed by other studies dealing with the tree growth of pine forests (Vacek et al., 2016, 2019). It is caused by the climatic conditions when the fastest xylem formation and radial increment were recorded (Mäkinen et al., 2003; Putalová et al., 2019). The photosynthesis rate is increasing during long and sunny summer days, which positively affects the tree biomass. In addition, increases in the rate of decomposition and nitrogen mineralization by increasing temperature and precipitation, improving nutrient availability (Huang et al., 2010; Zhang et al., 2010). The annual precipitation has affected the soil and air quality, while temperature increases influence the soil and water content via evaporation (Zheng and Hoefs, 1993). Therefore, It demonstrates positive relationship between annual maximum temperature, annual precipitation, and stem biomass (Usoltsev et al., 2020).

We further analyzed that the annual mean and minimum temperatures had a positive correlations with Mongolian Scots pine, (HP), and (SHP), plantation in *Figures 6* and *7a, b*. While, negative correlations were found with (STP) and (SRP) plantation in *Figures 6* and *7c, d*. The negative relationship for (STP), and (SRP), plantation of the (*Pinus sylvestris* var. *mongolica)* may be attributed to the potential effect of other factors, such as local environmental and physiological conditions (Freire et al., 2019; Wang et al., 2019). Mainly, during the cold and short seasons, tree growth also affects across climatic variables. We further highlighted that the annual minimum and mean temperature during the cold season were the key components limiting Mongolian Scots pine stress and shrinking plantation growth. Our findings are consistent with the previous reports (Qian and Qin, 2006). Moreover, It was also studied that biomass was well regulated by the amount of storage compounds and the current soil moisture regime (Fritts et al., 1965; Huang et al., 2010). The most sensitive physiological responses to water deficit are decreased turgor, slowed down elongation tree growth, and impaired protein metabolism, which ultimately represses cell division by inhibiting mitosis (Oberhuber et al., 1998; Kutschera and Niklas, 2013). Similarly, the utilization of stored carbohydrates increases when the temperature starts rising at the end of hot winter months (Su et al., 2015). Therefore, the present study emphasized that wet winter’s annual mean and minimum temperatures have a comparatively weak adverse impact on Mongolian Scots pine (STP), and (SRP), biomass (*Figs. 6* and *7c, d*). The possible explanation this plantation had fewer leaves; they could not do proper photosynthesis and respiration in the high snowfall weather during the winter season, which prolonged the snow melting process affecting tree development and biomass (Vaganov et al., 1999). It might be because the mean temperature and quantity of precipitation in the humid climatic region are very appropriate for tree development in the drought-resistant tree species, predominantly in the wettest quarter of the growing season (Fu et al., 2017; Khan et al., 2019). Previously it was reported that tree height decreases the inconstancy of stem biomass estimation (Feldpausch et al., 2012; Zhang et al., 2019a). The natural change of soil, species composition, solar radiations, and humidity and also affect biomass growth (Nascimbene et al., 2013; Hu et al., 2019).

A high amount of precipitation in the growing season and has the maximum annual temperature of the moistened season is moderately high. It sustains tree growth as well and has an effective relationship with tree biomass (Fu et al., 2017). *Pinus sylvestris* var. *mongolica* is a naturally drought-resistant tree species cultivated in northeastern China (Zhu et al., 2006; Fu et al., 2017). Therefore, it can smoothly maintain its survival at maximum precipitation and temperatures. Such conditions cannot restrain the tree and stem biomass (Hao et al., 2021). Besides, the loss of nutrients overflow has been affected by the high quantity of precipitation and humidity (Chen et al., 2015). Incorporating various stand levels of the tree and climatic variables could be better for more accurate precision of tree biomass prediction (Zeng and Tang, 2012; Dong et al., 2016). For this reason, in the current study, we determined only a simple tree biomass model together with climatic factors for conclusive stem biomass prediction.

Conclusion

This study was conducted in Horqin sandy land China, to find out impact of climatic variables on stem biomass and carbon stock of Mongolian Scots pine different health conditions from 1965-2019. Mongolian Scots pine healthy (HP), Sub healthy (SHP), Stress (STP), and Shrink (SRP), plantations have a strong correlations with annual precipitation (PP), and maximum temperature (T_{max}). Meanwhile, annual minimum temperature (T_{mini}) and mean temperature (T_{mean}), significantly correlated with (HP), and (SHP), plantations, but, negative correlations were found for (STP), and (SRP), plantations. Even though the melting of snow and high exposure to strong winds at the end of winter, it could be possible to slow down the growth of Mongolian Scots pine, (STP), and (SRK), plantation. Various parameters such as tree height, age, water, drought, nutrients, and competition among individuals tree also influence tree growth. In the future, to study the tree growth, one should consider some factors that highly affect the tree growth. Conclusively, the analyses highlighted that Mongolian Scots pine has a promising adaptability potential to the climate factors and stress condition of Horqin sandy land China. As a result of its uncomplicated nature, Mongolian Scots pine has been recommended for afforestation of reclamation sites, mainly on poor and dry sandy soils, exacerbated by the ongoing climate change.

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