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EVALUATION OF THE COMPOSITE EFFECTS OF BIOCHAR BASED ON SIGNIFICANCE VALUE OF COMPONENT TRAITS OF BASIL (*OCIMUM BASILICUM* L)

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Abstract

The effect of biochar on plant growth is a composite effect, which is made up of component traits effects. Two methods, integrating the significance values of component traits (ISVCT) and analytic hierarchy process (AHP) were used to evaluate the composite effect of biochar under three experimental conditions in this study. An experiment involving 3 types of biochar including commercial biochar (CB), hardwood biochar (HB) and willow chip biochar (WB) at 3 levels (potting mix amended 5, 10 and 20% biochar, V/V) was conducted to assess the effect of biochar on basil (*Ocimum basilicum* L.) growth. In the combination of the two conditions, the comprehensive effects of the 10 treatments were ranked exactly the same by using the two methods of ISVCT and AHP, indicating that ISVCT is simple and effective method for comprehensive evaluation of the composite effect. The results also showed that biochar of 20% CB had the best comprehensive effect on basil growth among 9 kinds of biochar treatments. Commercial biochar (CB biochar) is better than WB and HB. The results also showed that biochar has variable effects on basil growth depending on the type of biochar and application rates as well as experimental condition.

Introduction

Biochar is a by-product of pyrolysis (Valérie *et al.* 2013) and can be produced from a wide range of biomass including crop straw, woody material and other organic wastes (Luo *et al.* 2016). Because of the porous structure of biochar, large surface area, retention of water, nutrient holding capacity and high cation exchange capacity (Novak *et al.* 2012, Ding *et al.* 2017, Tan *et al.* 2017, Purakayastha *et al.* 2019) as well as improvement of soil permeability, the biochar has also been used as a soilless growing medium in hydroponic systems (Savidov and Nichols 2010). Therefore, application of biochar has been considered as a promising soil amendment to improve crop growth (Jiang *et al.* 2019). Effects biochar on plant growth are well studied. Biochar has been shown to promote plant productivity and yield and has beneficial effects on plant growth outbalance negative and neutral effects (Lori and Stanley 2013). It has been reported that the biochar effect varies with species (Valérie *et al.* 2013). There was also a report of biochar effects depending on the rate of application (Park *et al.* 2011). Most studies reported the effect of biochar on plant growth based on 1 - 2 special traits. Valérie *et al.*（2013）reported that biochar had inhibition effects on fresh and dry weights of lettuce.

Plant growth is a complex trait and is made up of several components. The effect of biochar on the complex trait should be a composite effect, which is composed of component traits effects. Effective evaluation methods are needed to evaluate the composite effect of biochar on plant growth. Analytic hierarchy process (AHP) is a system analysis method based on expert evaluation, which has been widely used in variety evaluation (Chen *et al.* 1992, Liu 2019). It divides the complex

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*Author for correspondence: <class2007ok@163.com>. [1]College of Life Science and Technology, Guangxi University, Nanning，Guangxi, China trait into the component traits and calculates the weight of each component trait to assist decision-making. It is an effective method combining quantitative analysis with qualitative analysis. However, this method needs complex judgment matrix operation and needs to input the relative weight values one by one for the paired component traits, which is the huge workload. It is still necessary to explore simple and effective methods to evaluate complex traits. More studies had highlighted the effect of biochar on the component trait such as specific trait. There are a few reports to evaluate the comprehensive effects of biochar on plant growth at present.

Therefore, the goals of the present study were (1) to propose a simple and effective method to assess biochar composite effect, and (2) to make a comprehensive assessment of biochar composite effect on basil growth.

Materials and Methods

In this experiment, three kinds of biochar, namely commercial biochar (CB), hardwood biochar (HB) and willow chip biochar (WB) were used. The commercial biochar is premium biochar (Black Owl Biochar (TM) and was purchased online in USA. Commercial biochar was produced using Pyrocycling^{TM} technology with the method described by Roy *et al.* (2000), which was derived from softwood bark of balsam fir (*Abies balsamea*), white spruce (*Picea glauca*) and black spruce (*Picea mariana*). The raw materials (species) of hardwood were produced from soft maple (*Acer rubrum*) and white oak (*Quercus alba*). Both hardwood and willow chip biochar were made in this laboratory at a temperature of 400ºC and 100 kPa pressure. After biochar of HB and WB had been ground and sieved to particle sizes ≤ 1 cm separately, they were added into the potting mixes according to the different proportions. The experiments were conducted in the ornamental flower greenhouse located at Cornell University, USA.

In this experiment, the control (CK) was a homemade potting mix made of 75% Lambert peat moss and 25% perlite. Three kinds of biochar (CB, HB and WB) were added to the homemade potting mix in three concentrations (5, 10 and 20%, v/v). So a total of 9 kinds of biochar-amended potting mixes were produced. Symbolically those were represented as 5, 10, 20% CB, 5, 10, 20% HB, 5, 10 and 20% WB.

Per cent total porosity were measured by saturating 9 kinds of biochar treatments with water and letting the water drain until the mass remained stable. The initial pH, bulk density and the electric conductivity (EC) were measured after mixing different concentrations of biochar into the potting mixes. The determination of pH, bulk density and EC is described briefly as follows: Determination of pH and EC value: 5.0 g soil sample was taken into a 100 ml conical flask and 50 ml water was added. It was oscillated on a water bath thermostatic oscillator at 25℃ for 30 min (oscillation frequency 180 R/min). It was filtered after standing. pH meter (PHS-3C) and conductivity meter (PHB-4) were used to determine the pH and EC value of the filtrate. Determination of soil bulk density: The method of cutting ring was adopted. The cutting ring filled with soil samples was directly dried to constant weight in a 105℃ drying oven, and the dried soil weight was weighed on the balance. The soil bulk density was calculated by the following formula: Bulk density (g/cm^3) = m (g)/V (cm^3). All measurements were repeated three times.

Potato dextrose agar (PDA) was used to culture fungus *Fusarium oxysporum* as previously reported (Cao *et al.* 2013). The fungus *Fusarium oxysporum* was inoculated on the plate of PDA medium at 25°C in the dark. Fully grown 7.5 culture plates of *F. oxysporum* were taken into a homogenizer. After breaking the plates slightly, 1650 ml water was added and stirred to make fungal suspension, the concentration of which reached 1 × 10^5 spores/ml. Including control and 9 potting mixes a total of 10 samples were taken and put into 10 plastic bags. To each of these potting mixes 150 ml fungal suspension was added and mixed well. After being made ready, all these 10 plastic bags were placed into a greenhouse set with a temperature of 25°C. After two days the potting mix in each plastic bag was carefully placed into 10 different culture pots. Later on, the basil seedlings were transplanted into the pots.

The experiment was divided into 10 treatments, which were carried out under two conditions (inoculated with *Fusarium oxysporum* and uninoculated). Each treatment was repeated 10 times. In short, seeds of basil (*Ocimun basilicum* L.) were purchased from a Wal-Mart Super market in downtown Ithaca, USA. Then seeds of basil were sown in two multicellular trays (200 cells, 14 ml per cell) containing the control potting mix on 20 October, 2015. The four-inch pots were full of different types of potting mixes, about 0.4 liters. After 32 days (21 November, 2015), 20 seedlings were used to evaluate the effect of each type of biochar, of which 10 seedlings were transferred into four-inch pots containing different types of potting mixes without *F. oxysporum*; the other 10 seedlings were transferred into four-inch pots containing different types of potting mix with *F. oxysporum*, one seedling per pot.

The formulations and application method of fertilizer solution are as follows. Firstly, the Jacks stock solution was prepared by accurately weighing 750 g Peters Professional Peat Lite Special (20-10-20, Everris Na Inc.,USA) followed by dissolving it in a portion of deionized water (DI H_2O) and then making the final volume up to 15 litre. Jacks stock solution contains nutrients of essential microelements such as molybdenum, boron and macroelements such as nitrogen, phosphorus and potassium that promote root and shoot growth. So, a Jacks stock solution having a concentration of 10,000 ppm was made ready to use. Secondly, 80 litre of fertilizer solution was prepared, into which 1200 ml Jacks stock solution was added and then was made to a final volume of 80 litre by adding DI H_2O to it. Basil seedlings were gown under natural light in a greenhouse at a temperature of 25°C. Fertilizer solution was poured once a day to the experimental pots until the nutrient solution overflows from the pots.

Eight traits such as root dry weight (RDW), shoot dry weight (SDW), shoot fresh weight (SFW), plant height (PH), leaf width (LW), leaf length (LL) and onset days (OD), disease degree (DD) were scored under the conditions with and without *F. oxysporum* inoculation. For the convenience, the traits scored under the condition of inoculation with *F. oxysporum* were marked as “trait+F”. And the traits scored under the condition without *F. oxysporum* were marked as “trait-F”. Traits of plant height, leaf length and leaf width were investigated on 25 December, 2015 after about one month of seedlings transplanting. Plant height refers to the height from the surface of the potting mix to the top of the topmost leaf. Leaf length refers to length from the tip to the petiole of the longest leaf among whole basil plant leaves. Leaf width is the widest length in the middle of the longest leaf. Onset days (OD) refers to the time when wilting symptoms appear due to the action of *F. oxysporum,* when leaves of basil change from firm, green leaves to drooping and yellow leaves, except for the upper two leaves of basil. Basils grown in different potting mixes were harvested on 4 January, 2016 and separated into roots and shoots. The shoot samples were weighed and shoot fresh weights were obtained.

The roots were carefully rinsed with tap water. Then water on the root surfaces was absorbed with absorbent paper. The root and shoot samples were put into paper bags separately and dried in an oven at 80°C for 3 days. Then the data of root and shoot dry weights were obtained.

Data of all treatments were analyzed using one-way ANOVA for testing the significance of different traits of basil grown in 10 kinds of treatments. When the differences were considered to be significant ($p < 0.05$), the multiple comparisons of Fisher LSD were performed to detect significant differences at $p < 0.05$, and the results of multiple comparisons were marked with letters. Correlation analysis and ANOVA were performed using SPSS Statistics 17 (IBM). The comprehensive effects of the nine treatments and control (CK) were evaluated by using the analytic hierarchy process (AHP) software and the method of integrating the significance values of component traits (ISVCT).

The correlation analysis of the traits was carried out under the conditions with and without *F. oxysporum* inoculation. Traits not related to the trait of SDW were selected as the component factors of basil growth. When running the AHP software, the weight of pairwise component factors was based on the significance assignment ratio, and 9 kinds of treatments and CK were used as 10 alternatives. The evaluation results based on the two methods were compared.

By multiple comparisons of each trait of basil grown in potting mixes, the component trait significance was marked by a method of marked letter with different letters，such as a, b, c, d, ab, bc and cd, respectively. In order to compare the comprehensive effects of different biochar, the component trait values marked with different letters needed to be reassigned. Different letters could be assigned according to the order of the letter marked in multiple comparisons, in which the first marked letter was assigned the maximum value, and the last marked letter was assigned the minimum value. The letters marking significance, a, b, c, d or two different letters, were assigned in the order from large to small. The assignment of double letters was the average of the sum of the assignments of the two single letters. The values of different letters were assigned as follows: a = 4, b = 3, c = 2, d = 1, ab = 3.5, bc = 2.5 and cd = 1.5. In this way, each component trait corresponded to different assignments.

The total score was used to evaluate the composite effect of biochar. In the method of ISVCT, the total score of each treatment is the weighted average of the significant value of these component factors. Under the condition without *F. oxysporum* inoculation, the weights of the three components SDW, RDW and LL were set to 0.7, 0.1 and 0.2, respectively. So, the score F = 0.7 × SDW + 0.1 × RDW + 0.2 × LL. While under the condition with *F. oxysporum* inoculation, the weights of the four components SDW, PH, LW and OD were set to 0.5, 0.1, 0.2 and 0.2, respectively. So, the score + F = 0.5 × SDW + 0.1 × PH + 0.2 × LW + 0.2 × OD. The more the total score of a treatment is the higher the ranking of the treatment.

Results and Discussion

Correlation analysis was carried out on the traits under the conditions with and without *F. oxysporum* inoculation. The results are presented in Tables 1 - 2.

For the complex trait of basil growth, SDW is the most typical component factor trait of plant growth. The traits related to SDW were not selected as the component factors of basil growth, while the factors not related to SDW were identified as the component factors of basil growth. Just as shown in Table 1, two traits, LL and RDW, were not related to SDW. So, three traits, LL, RDW and SDW, were identified as the component traits of basil growth under the condition without *F. oxysporum* inoculation. Similarly, four traits PH, LW, OD and SDW, were also identified as the component traits of basil growth under the condition with *F. oxysporum* inoculation.

Compared with the control, three kinds of growth effects of biochar on basil growth, the promoting effect, the inhibition and no effect were observed (Table 3). In one hand, 20% CB had promoting effect on SDW + F and LW + F. 10% WB also had a promoting effect on OD. *F. oxysporum* is a pervasive soil-borne phytopathogen that can cause serious diseases such as vascular wilt, root rot, and damping off in many plants (McGovern 2015). So the promoting effect of biochar on OD indicated that some biochar has the effect of suppressing pathogenic microorganism. On the other hand, the inhibition effects of biochar was also observed, such as the inhibition effects of 5% HB on SDW + F, PH + F and LW + F. At the same time, 10% HB had no significant effect (neutral effect) of on SDW + F, PH + F.

Table 1. Correlation coefficient of traits under the condition without *F. oxysporum* inoculation.

Traits	PH-F	LW-F	LL-F	SFW-F	SDW-F	RDW-F
PH-F	1					
LW-F	0.025	1				
LL-F	0.121	0.220	1			
SFW-F	0.482	0.248	0.243	1		
SDW-F	0.478*	0.365*	**0.104**	0.547*	1	
RDW-F	0.142	–0.090	–0.227	–0.097	–**0.063**	1

The correlation between traits was based on r = 0.288 ($p < 0.05$, n = 48).

Table 2. Correlation coefficient of traits under the condition with *F. oxysporum* inoculation.

Traits	PH + F	LW + F	LL + F	SFW + F	SDW + F	RDW + F	OD	DD
PH+F	1							
LW+F	–0.019	1						
LL+F	0.423	0.158	1					
SFW+F	0.257	0.395	0.614	1				
SDW+F	0.120	0.259	0.394*	0.434*	1			
RDW+F	0.060	–0.186	0.315	0.042	0.291*	1		
OD	0.336	0.189	0.537	0.626	0.237	0.071	1	
DD	–0.045	–0.347	–0.068	–0.159	–0.379*	0.191	0.047	1

The correlation between traits was based on r= 0.288 ($p < 0.05$, n = 48).

Table 3. The effects of component traits of basil grown in potting mixes inoculated with *F. oxysporum.*

Type	SDW + F (g)	PH + F (cm)	LW + F (cm)	OD + F (day)
5%CB	5.58 ± 0.42ab	32.63 ± 0.23b	3.50 ± 0.33bc	62.33 ± 2.33ab
10%CB	5.21 ± 0.21c	36.50 ± 0a	2.60 ± 0.02cd	62.00 ± 3.00b
20%CB	5.80 ± 0.13a	34.38 ± 1.06ab	4.38 ± 0.26a	65.00 ± 7.00ab
5%WB	5.32 ± 0.32bc	31.38 ± 0.06bc	3.18 ± 0.12bc	61.33 ± 16.33b
10 %WB	5.45 ± 0.17b	33.83 ± 0.06ab	3.48 ± 0.14bc	65.33 ± 1.33a
20%WB	5.34 ± 0.22bc	31.13 ± 0.06bc	3.03 ± 0.14c	59.00 ± 0b
5%HB	4.95 ± 0.18d	29.75 ± 0.08c	2.43 ± 0.09d	59.00 ± 0b
10%HB	5.32 ± 0.11bc	33.88 ± 0.23ab	3.13 ± 0.06c	59.00 ± 0b
20%HB	5.57 ± 0.21ab	30.88 ± 0.73bc	3.20 ± 0.06bc	61.33 ± 0.33b
Control	5.35 ± 0.14bc	34.13 ± 0.40ab	3.68 ± 0.29b	61.33 ± 6.33b

+F indicates basil grown in potting mix inoculated with *F. oxysporum*. The values behind "±" values in the table represent one standard error of the mean (n = 10). SDW: Shoot dry weight; PH: Plant height; LW: leaf width; OD : Onset day.

Under the condition without *F. oxysporum* inoculation, the performances of 9 kinds of treatments on the component traits are shown in Table 4. Different types of potting mixes showed three effects, the promoting effect, the inhibition effect and no significant effect. For the trait of LL-F, except for the beneficial effect of 10% CB, the others 8 types of biochar had no significant effect on this trait. For the traits of SDW-F, 10% CB, 20% CB and 10% WB had no significant effect on them compared with the control, the others 6 treatments showed a inhibition effect. For the trait of RDW-F, biochar of 5% CB and 20% HB had promoting effect, the other 7 treatments (10% CB, 20% CB, 5% WB, 10% WB, 20% WB, 5% HB, 10% HB) had no significant effect.

For the same biochar, these effects were also observed and its performance varied with different traits. For example, 5% CB had the promoting effect on RDW-F while had no significant effect on SDW-F and LL-F (Table 4). Except for the promoting effects on LL-F, 10% CB had no significant effects on the other 2 traits. Except for the promoting effects on SDW-F, 20% CB had no significant effects on the other traits. The 5% HB had no significant effects on these 3 traits. In this study, the negative effects of excessive application of biochar was also reported. Excessive application of biochar will lead to the inhibition of crop growth (Schmidt and Noack 2000). Certain biochar application could decrease plant growth due to decrease in nutrient availability to plants. The reasons for the decrease in soil nutrient availability caused by excessive application of biochar include elevating soil alkalinity (Songkrit *et al*. 2014, Kim *et al*. 2016) and the C/N ratio of soil (Lehmann *et al*. 2003).

Table 4. The effects of component traits of basil grown in potting mixes without *F. oxysporum* inoculation.

Type	SDW-F(g)	RDW-F(g)	LL-F(cm)
5%CB	6.45 ± 0.02b	1.95 ± 0.02a	6.88 ± 0.06b
10%CB	6.90 ± 0a	1.61 ± 0.03b	7.88 ± 0.06a
20%CB	6.90 ± 0a	1.76 ± 0.02ab	7.13 ± 0.23b
5%WB	6.48 ± 0b	1.73 ± 0.04ab	7.13 ± 0.06b
10 %WB	6.67 ± 0ab	1.74 ± 0.03ab	7.75 ± 0.25ab
20%WB	6.51 ± 0b	1.59 ± 0.01b	7.50 ± 0.33ab
5%HB	6.47 ± 0b	1.59 ± 0.03b	7.43 ± 0.26ab
10%HB	6.45 ± 0b	1.74 ± 0.02ab	7.23 ± 0.07b
20%HB	6.45 ± 0b	1.93 ± 0.04a	6.88 ± 0.06b
Control	6.67 ± 0.01ab	1.60 ± 0.02b	6.88 ± 0.06b

-F indicates basil grown in potting mix without *F. oxysporum*. The values behind "±" symbol in the table represent one standard error of the mean (n = 10). The letters behind standard error represent different significance of this component factor trait. SDW: Shoot dry weight; RDW: Root dry weight; LL: Leaf length.

The dose effect and peak effect of biochar were observed under the conditions with and without *F. oxysporum* inoculation. In this study, the performance of the biochar varied with amount of applications rates. The effects of biochar on basil traits increased as the amount of biochar application rates increased. For example, under the condition inoculated with *F. oxysporum* the effects of biochar on SDW+F increased significantly (4.95, 5.32 and 5.57 g) with the increase of HB-type of biochar (Table 3). The effects of HB-type of biochar on RDW-F as shown in Table 4 were also like this. Some researchers reported the dose effect of biochar. The dose effect of biochar on oat fresh and dry biomass (Wagner and Kaupenjohann 2014), on plant growth (Park *et al.* 2011) and on heavy metal bioavailability (Fellet *et al.* 2011), had been reported. Our results are consistent with previous results.

While for the trait of LL-F, with the increase of HB-type of biochar, the effects on LL-F decreased significantly (7.43, 7.23 and 6.88 g). With the increasing concentration of a certain type of biochar, the effect of the biochar does not show the dose effect, but a peak phenomenon or a phenomenon of maximum value, which is called peak effect of biochar. For example, with the increasing concentration of CB-type of biochar, the effect of 10%CB on LL-F showed a peak phenomenon (6.88, 7.88 and 7.13 g). Generally speaking, the dose effect should show a trend rather than a specific concentration, and the peak effect is the direct expression of the optimal concentration. The optimization of some kind of biochar is to find the peak value during dose effect for some kind of biochar.

In this study, the method of integrating the significance values of component traits (ISVCT) was used to evaluate the composite effects of biochar treatments on basil growth. Tables 3 and 4 showed the significance of the component traits of basil using different marked letters. Different assignments to these letters are presented in Tables 5 and 6 according to their letter type of significant difference. The composite effect of each treatment (total score) is the weighted average of the significant value of these component traits.

Table 5. Three component trait assignment and the composite effects of ten treatments on basil growth under the potting mixes without *F. oxysporum* inoculation.

Type	SDW-F	RDW-F	LL-F	Score-F
5%CB	b(3)	a(4)	b(3)	3.10
10%CB	a(4)	b(3)	a(4)	3.90
20%CB	ab(3.5)	ab(3.5)	b(3)	3.75
5%WB	b(3)	ab(3.5)	b(3)	3.05
10%WB	ab(3.5)	ab(3.5)	ab(3.5)	3.15
20%WB	b(3)	b(3)	ab(3.5)	3.10
5%HB	b(3)	b(3)	ab(3.5)	3.10
10%HB	b(3)	ab(3.5)	b(3)	3.05
20%HB	b(3)	a(4)	b(3)	3.10
Control	ab(3.5)	b(3)	b(3)	3.35

The number after each letter represents the significance value of this component factor trait. Trait abbreviation explanations are the same as Table 4. Score-F = 0.7 × SDW + 0.1 × RDW + 0.2 × LL.

According to the total score, under the condition without *F. oxysporum* inoculation biochar such as 10%CB and 20%CB had the higher scores compared with CK, while 5%WB and 10%HB had the lower scores compared with CK (Table 5). As shown in Table 6, under the condition with *Fusarium* inoculation, 20%CB and 10%WB had the higher scores compared with CK. While 20%WB and 5%HB had the lower scores compared with CK. Combined with two conditions of with and without *F. oxysporum*, biochar of 20%CB and 10%WB had the best performance compared with the control. The worse performances of biochar were 20%WB, 10%HB and 5%HB.

Considering the effects of biochar under both *F. oxysporum* inoculated and uninoculated conditions, the results of comprehensive evaluation of the biochar composite effects are shown in Table 7.

Table 6. Four component trait assignments and the composite effects of 10 treatments on basil growth under the potting mixes with *F. oxysporum* inoculation.

Type	SDW+F	PH+F	LW+F	OD	Score+F
5%CB	ab(3.5)	b(3)	bc(2.5)	ab(3.5)	3.25
10%CB	c(2)	a(4)	cd(1.5)	b(3)	2.30
20%CB	a(4)	ab(3.5)	a(4)	ab(3.5)	3.85
5%WB	bc(2.5)	bc(2.5)	bc(2.5)	b(3)	2.60
10%WB	b(3)	ab(3.5)	bc(2.5)	a(4)	3.15
20%WB	bc(2.5)	bc(2.5)	c(2)	b(3)	2.50
5%HB	d(1)	c(2)	d(1)	b(3)	1.50
10%HB	bc(2.5)	ab(3.5)	c(2)	b(3)	2.60
20%HB	ab(3.5)	bc(2.5)	bc(2.5)	b(3)	3.10
Control	bc(2.5)	ab(3.5)	b(3)	b(3)	2.80

The number after each letter represents the significance value of this component factor trait. Trait abbreviation explanations are the same as Table 3. Score + F = 0.5 × SDW + 0.1 × PH + 0.2 × LW + 0.2 × OD.

Table 7. The comprehensive effects of 10 treatments on basil growth under three experimental conditions (inoculation, non-inoculation and combination of two conditions) used by ISVCT method.

Type	Score+F	Score-F	Total score
5%CB	3.25	3.10	6.35
10%CB	2.30	3.90	6.20
20%CB	3.85	3.40	7.25
5%WB	2.60	3.05	5.65
10%WB	3.15	3.50	6.65
20%WB	2.50	3.10	5.60
5%HB	1.50	3.10	4.60
10%HB	2.60	3.05	5.65
20%HB	3.10	3.10	6.20
Control	2.80	3.35	6.15

The total score is to the sum of the score-F and the score+F.

According to the score+F, the 10 treatments under the condition with *F. oxysporum* inoculation were ranked according to the score+F as follows (Table 6): 20% CB, 5% CB, 10 % WB, 20% HB, Control, 5% WB, 10% HB, 20% WB, 10% CB and 5% HB. While under the condition without *F. oxysporum* inoculation, the 10 treatments were ranked according to the score-F as follows: 10% CB, 10% WB, 20% CB, control, 20% WB, 5% HB, 5% CB, 20% HB, 5% WB and 10%HB (Table 5). Combination of the two conditions with and without *F. oxysporum*, the 10 treatments were ranked according to the total score as follows: 20% CB, 10% WB, 5% CB, 20% HB, 10% CB, control, 10% HB, 5% WB, 20% WB and 5% HB (Table 7). 20% CB (7.25) showed the best comprehensive effect on basil growth, while 5%HB (4.60) showed the worst comprehensive effect on basil growth.

The method of AHP was used to evaluate the comprehensive effects of 10 treatments under three conditions (inoculation, un-inoculation and combination of two conditions). The optimal biochar hierarchical analysis model under three conditions is shown in Fig. 1.

It can be seen from Fig. 1 that the weight value of each component factor was different under the three conditions, in which the value of SDW was the largest weight. Under the three conditions (condition with *F. oxysporum* inoculation, condition without *F. oxysporum* inoculation and combining two conditions), the method of AHP was used to give the ranking of 10 treatments, as shown in Table 8.

It can be seen from Table 8 that only rank 3 and rank 4 were reversed among the 10 rankings given by the two methods under the condition with *F. oxysporum* inoculation and rank 2 and rank 3 were reversed without *F. oxysporum* inoculation, while the other 8 rankings were completely the same. In the combination of the two conditions, the comprehensive effects of the 10 treatments were ranked exactly the same by the two methods. This indicated that ISVCT is an effective method for comprehensive evaluation of complex trait. In addition, in combination of the two conditions, 20%CB had the best comprehensive effect on basil growth, while 5%HB had the worst comprehensive effect on basil growth.

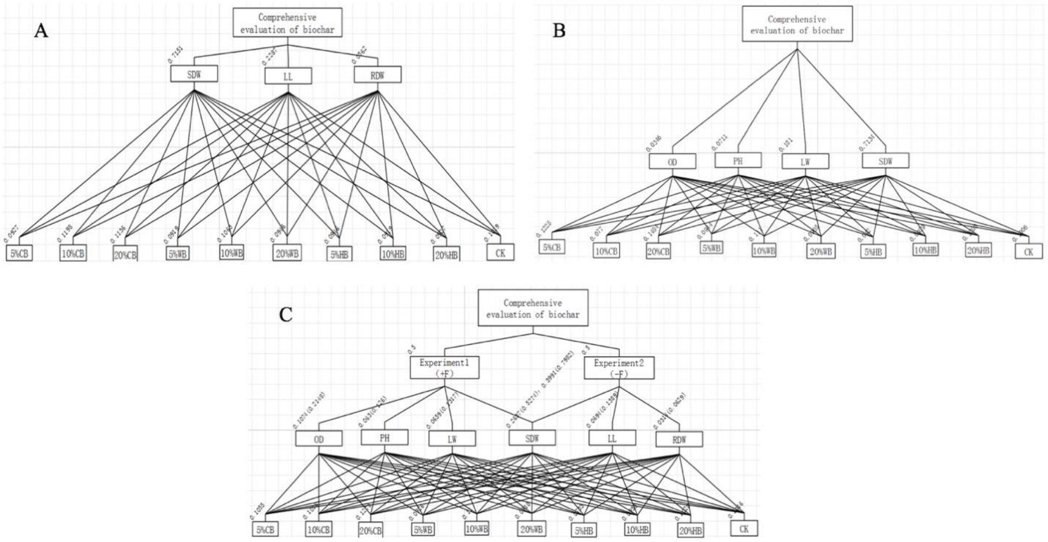

Fig. 1. The optimal biochar hierarchical analysis model under three conditions (inoculation, un-inoculation and combination of two conditions). A: Under the condition without *F. oxysporum* inoculaiton. B: Under the condition with *F. oxysporum* inoculaiton. C: Combining two the conditions. The number above the middle layer represents the weight value of each component trait. The number above the bottom layer represents the conclusion value.

As the complex trait, since basil growth is composed of component traits, it is necessary to decompose complex trait into single component trait for evaluating the composite effect. AHP is based on the complex operation of judgment matrix and needs to determine weight values of the evaluation factors before calculating the comprehensive evaluation value of the varieties, which will be a huge workload for multiple alternatives and multiple component traits (evaluation factors).

Table 8. The comprehensive effects of ten treatments on basil growth under three experimental conditions (inoculation, un-inoculation and combination of two conditions) used two methods.

Condition without *F. oxysporum* inoculation				Condition with *F. oxysporum* inoculation				Combining two conditions			
Ranking by ISVCT	Score-F	Ranking AHP	Conclusion value-F	Ranking by ISVCT	Score+ F	Ranking AHP	Conclusion value+F	Ranking by ISVCT	Total score	Ranking AHP	Conclusion value
10%CB	3.90	10%CB	0.1198	20%CB	3.85	20%CB	0.1484	20%CB	7.25	20%CB	0.1273
10 %WB	3.50	20%CB	0.1136	5%CB	3.25	5%CB	0.1225	10 %WB	6.65	10%WB	0.1100
20%CB	3.40	10%WB	0.1063	10 %WB	3.15	20%HB	0.1208	5%CB	6.35	5%CB	0.1055
Control	3.35	CK	0.1019	20%HB	3.10	10%WB	0.1110	20%HB	6.20	20%HB	0.1028
20%WB	3.10	20%WB	0.0946	CK	2.80	CK	0.1006	10%CB	6.20	10%CB	0.1018
5%HB	3.10	5%HB	0.0946	5%WB	2.60	5%WB	0.0944	CK	6.15	CK	0.1016
5%CB	3.10	5%CB	0.0927	10%HB	2.60	10%HB	0.0929	10%HB	5.65	10%HB	0.0933
20%HB	3.10	20%HB	0.0927	20%WB	2.50	20%WB	0.0905	5%WB	5.65	5%WB	0.0926
5%WB	3.05	5%WB	0.0919	10%CB	2.30	10%CB	0.0770	20%WB	5.60	20%WB	0.0918
10%HB	3.05	10%HB	0.0919	5%HB	1.50	5%HB	0.0420	5%HB	4.60	5%HB	0.0733

A simple and effective method based on the significance value of component traits, a method of integrating the significance values of component traits (ISVCT), was proposed in this study. The procedures of using the ISVCT method are as follows: (1) Determine the most typical component trait. When comprehensive effects of multiple alternatives are evaluated on a complex trait, the most typical component factor trait of the complex trait is needed to determine among many traits. (2) Determine the component factors of the complex trait. The correlation analysis is made for many traits, among which the traits not related to typical component factors are identified as the component traits (evaluation factors) of the complex trait. (3) The significance of these component traits are marked with letters. Variance analysis and multiple comparisons are performed on these component traits. The significance of these component traits is marked with different letters according to their mean value. (4) Assign values to different letters. These different letters and letters combinations can be assigned to different values. So the component traits will correspond to a number of significance values. (5) Set the relative weight values of the component traits. The relative weight values of these component traits are set by comparing the typical component trait. (6) Calculate the total score of each alternative. The weighted average of the component traits of each alternative is the total score of each alternative. (7) Rank the alternatives. Alternatives are ranked using the total score.

The comprehensive effects of 9 biochar treatments on basil growth were evaluated under three conditions (under the condition of inoculation, without inoculation, the combined two conditions). It can be seen from Table 8 that under different experimental conditions, the performance of 9 biochar treatments is different. For example, take 10%CB as an example. Under the inoculated condition, the comprehensive effect of 10%CB ranked the ninth among the 10 treatments, and the comprehensive effect of 10%CB ranked the first under the uninoculated condition. When the two conditions were combined, the comprehensive effect of 10%CB ranked fifth among the 10 treatments. This indicated that the comprehensive effect of biochar on basil growth was related to the experimental conditions.

As shown in Table 8, under the combination of the two experimental conditions, the comprehensive effects of 20%CB, 10%WB, 5%CB, 20%HB and 10%CB ranked before the control. This indicated that the comprehensive effects of these five kinds of biochar treatments were better than that of the control, in which 20%CB showed the best comprehensive effect on the growth of basil. However, 10%HB，5%WB，20%WB and 5%HB ranked behind the control. This indicated that the comprehensive effects of these four kinds of biochar treatments were worse than that of the control, in which 5%HB showed the worst comprehensive effect on basil growth. In addition, the comprehensive effects of 20%CB, 5%CB and 10%CB were better than the control, indicating that CB type of biochar was better than the other two types of biochar (HB and WB).

Under the combining conditions of inoculation and non-inoculation, the comprehensive effect ranking of the 10 treatments given by the method of ISVCT was the same as that of AHP, indicating that ISVCT is a simple and effective method. At the same time, it was observed the ranking of the comprehensive effects of 10 kinds of treatments under the conditions with and without *F. oxysporum* inoculation was slightly different, indicating that the ranking of the comprehensive effects of the biochar depends on the experimental conditions. In addition，the ranking of the comprehensive effects of the biochar also depends on the type and concentration of biochar.

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