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Effect of Cement Content in Vegetation Concrete on Soil Physico-chemical Properties, Enzyme Activities and Microbial Biomass

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ABSTRACT

The vegetation concrete eco-restoration technology is a slope restoration technique used to strengthen slope stability and restore slope vegetation. The key issue in the entire technique is the composition of vegetation concrete suitable to the slope stability and re-vegetation. The objective of this study is to determine the appropriate cement content in vegetation concrete in the application of vegetation concrete eco-restoration technology. A series of systematically designed experiments were conducted on *Cynodon dactylon* and *Medicago sativa* with different cement content treatments to assess the effects of cement on the soil physico-chemical properties, enzyme activities and microbial biomass. The soil organic matter (SOM), soil total nitrogen (TN), enzyme activities and microbial biomass were significantly lower in high cement content treatments. A multi-index fuzzy comprehensive evaluation model was established to calculate the *SBAI* value, which can comprehensively evaluate how soil enzyme and microbial biomass characterized the quality change under different cement contents. The *SBAI* values of high cement content vegetation concrete were smaller than those of low cement content. Moreover, the *SBAI* value declined sharply when cement content reached 8%. And the *SBAI* values of unplanted sites were smaller than planted sites. The research found the quality of vegetation concrete reduced remarkably when cement content exceeded 8%. The 4-8% cement content appeared to be the appropriate range of cement content in vegetation concrete for the two studied species when plant growth and soil quality be taken into account.

INTRODUCTION

In past decades, construction has disturbed countless slopes due to building of highways, mines, hydropower projects and urban zones, to meet the needs of an increasing population and economic development. The continuing expansion of construction projects is accompanied by massive disturbed slopes that are prone to numerous negative effects on ecological environment, such as vegetation destruction, topographic and hydrological changes, soil erosion and landslides (Ye et al. 2005, Anderson et al. 2007, Zhao & Zhao 2009, Xu et al. 2012). Traditional slope treatment can play a good reinforcement effect on disturbed slopes, but still leave huge bare slope surfaces that negatively impact ecological functions and landscape structure (Ye et al. 2005, Zhao & Zhao 2009). Experts focus their research on how to achieve the orderly development of construction projects that protect the environment (Xu et al. 2002, Zhou & Zhang 2003, Lui et al. 2005, Zhao & Zhao 2009, Xu et al. 2012, Medl et al. 2017). Slope ecological restoration techniques are well suited for project needs since they can improve slope stability, control slope erosion and enhance landscape value (Andreu et al. 2008, Ng et al. 2011, Xu et al. 2012, Chok et al. 2015, Chen et al. 2015b, Zhao et al. 2017). After years of development, diverse environment-friendly and cost-effective techniques have been extensively applied to mitigate the problems generated by soil instability in project (Xu et al. 2002, Huang et al. 2010, Luo et al. 2012, Li et al. 2017). Liu et al. (2005) classified the representative techniques into hydroseeding (García-Palacios et al. 2010, Thomas & Skousen 2015), direct planting system (Dudai et al. 2006, Chong & Chu 2007), reinforced soil (Xu et al. 2002, Hejazi et al. 2012, Luo et al. 2012), mulching system (Ahn et al. 2002) and cellular system (Mitchell et al. 2003).

The vegetation concrete eco-restoration technology can restore vegetation by spraying vegetation concrete on slope surface and can be classified as reinforced soil technology

(Xu et al. 2002). This kind of technique often involves the application of soil mix, either in a form of layer or compartment, as greening substrate on the slope surface (Ng et al. 2011, Luo et al. 2012, Xu et al. 2017). Vegetation concrete is a typical soil mix characterized by strong scour resistance, high fertility, and reasonable distribution of solid-liquid-vapour phases. It is a mixture comprising of planting soil, cement, organism of habitat material, amendment of habitat material, plant seeds and water (Xu et al. 2012). Organism of habitat material is a granular substance which is obtained by smashing, mixing and fermenting the raw materials such as farmyard manure, straw, chaff, sawdust, dross and other natural organic manure. It is the nutrient source and helps increase the porosity of vegetation concrete (Li 2008, Liu et al. 2012). The patented product amendment of habitat material is devised by China Three Gorges University (CTGU). It is a fine granular substance used to improve the microbial environment, pH value, fertility, water-retaining property, structure and other physical and chemical properties of vegetation concrete (Xu et al. 2012). The solidification of cement can increase structural stability of habitat material in a short time and enable faster development of resistance to erosion (Xu et al. 2007, Xia et al. 2011a). But cement' hydration would make habitat material become strongly alkaline and significantly influence the growth of plants (Xu et al. 2012, Chen et al. 2013). The appropriate proportion of vegetation concrete is critical in the entire technique. Numerous experiments have been conducted to determine the appropriate component ratios of vegetation concrete from the perspective of stability and erosion resistance of disturbed slope (Xu et al. 2007, Xia et al. 2011a), optimize the composition and ratio of vegetation concrete available in alpine and cold area (Liu et al. 2013), screenproper slope protection plants in terms of seed germination and seedling establishment (Chen et al. 2013). When considering slope strength and erosion resistance ability, the optimal proportion of cement is 8%-10% (Xu et al. 2012). In terms of achieving best seeding growth in vegetation concrete, the suitable cement content is lower than 8% (Chen et al. 2013). Fewer studies that investigate the changes of soil quality associated with cement content in vegetation concrete have been published in recent years.

Soil quality is represented by the soil's physical, chemical and biological properties and is sensitive to anthropogenic disturbance (Freckman & Virginia 1997, Anderson 2003, Seker et al. 2017). It can be used to indicate the capacity of soil to sustain biological productivity, promote environmental quality, and maintain plant and animal health (Doran & Zeiss 2000). The evaluation of soil quality is essential for ecological restoration and environmental stability in disturbance regions. de Medeiros et al. (2017) reported that determining sensitive and rapid indicators can response the quality of soil, which is the focus of future research. Since, soil functioning and sustaining soil fertility is governed largely by biotic component, the soil biological indicators include soil microorganisms, soil enzymatic activity and soil animals, which are generally be used as a stability indicators for quick recognition of an environmental change (Anderson 2003, Tang et al. 2007). Thus, to improve our knowledge of how cement content in vegetation concrete influences the soil quality, an experiment was set up to examine the biological indicator of vegetation concrete' response to cement content change. Pioneer plant species, *Cynodon dactylon* and *Medicago sativa* were seeded to reflect plant adaptations in this experiment because they have the superiority in fast growing with developed root systems and adaptation to environment, and therefore, particularly suitable for ecological restoration (Xia et al. 2011b, Chen et al. 2013, 2015a). Studies on these two plants cope up with cement in the vegetation concrete in terms of soil biological indicators have instructional significance in determining the appropriate cement content range in the application of vegetation concrete eco-restoration technology. The objective of the present study is to answer two specific questions: (1) How soil quality is affected by different cement contents in vegetation concrete? (2) What is the appropriate component ratio of vegetation concrete that can satisfy the engineering demand?

MATERIALS AND METHODS

Experimental design: In order to evaluate the influence of cement on the soil physico-chemical properties, enzyme activities and microbial biomass of habitat material of vegetation concrete eco-restoration technique, a series of comparative experiments were conducted on different cement content in vegetation concrete. The comparative experiment was carried out in CTGU and the experimental plots were set inside the greenhouse.

The plant soil used in the experiment was taken from Cuipinghill. The soil type was yellow brown soil and alkaline soil. The soil natural moisture content was 24% and the soil natural density was 1.78 g/cm^3. Organism of habitat material used in this research was sawdust. After mixing soil, cement, organism of habitat material and amendment of habitat material, the vegetation concrete was layered flat on the plots. The seven cement content treatments were 0%, 2%, 4%, 6%, 8%, 10% and 12% to soil weight. The component ratio of other materials was soil:organism of habitat material:amendment of habitat material = 100:5:5 (Xu et al. 2012). A total of 14 plots were prepared (1 m in length, 0.3 m in width), each filled with vegetation concrete around 10 cm depth and just the top 2 cm layer included seeds. The seeding density of *Cynodon dactylon* and *Medicago sativa* was 10 g/m^2 and 5 g/m^2. Seeds were irrigated well once every two days during the experiment to keep the experiment ongoing. To prevent the interspecific competitive effect, the experimental treatment plots of each species were separated from each other (Chen et al. 2015a).

Experimental tests: The experiment began in August 2015. After eight months of united management by regular watering and weeding, the plant height and plant density were measured and calculated *in situ*. Soils were sampled from each plot by cylinders of 5 cm in diameter and 5 cm in height. Three samples per plot were collected through a randomized sampling strategy and completely mixed into one composite soil sample. The soil samples were sieved through a 2 mm mesh to remove roots, stone and other debris and immediately divided into two subsamples. One soil subsample was air-dried for the determination of soil physico-chemical properties and soil enzyme. The other subsample was stored at 4°C for the analyses of soil microbial biomass. However, for climate and planting time reasons, there was no soil animal appeared in vegetation concrete. So the soil biological indicators used in this study did not include soil animals.

Soil physico-chemical analysis was conducted according to Zhang (2007). The soil pH was measured in a soil-water suspension (soil:water = 1:2.5) using an automatic acid-base titrator. The soil organic matter (SOM) was measured with potassium dichromate oxidation-ferrous sulphate titrimetry. The soil total nitrogen (TN) was determined by the Kjeldahl method. Soil enzyme activity was estimated using the Guan (1986) method. The soil urease was obtained by phenol-sodium hypochlorite colorimetric method. The soil invertase was determined by 3.5-dinitrosalicylic acid colorimetric method (DNS method). The soil phosphatase was obtained by disodium phenyl phosphate colorimetric method. The determination of soil microbial biomass carbon (MBC) and soil microbial biomass nitrogen (MBN) were determined by fumigation-extraction method through procedures described by the Institute of Soil Science of Chinese Academy of Sciences (ISSCAS 1978).

Multivariance analysis of soil biological activity: The soil enzyme activity and the soil microbial biomass reflect different soil biological characteristic and their impact on soil function is a gradual process. The single index fuzzy evaluation model was established to reflect the performance of each index based on fuzzy mathematics principle. The measured value of each soil biological index could be converted into a numeric between 0 and 1. The soil biological index has no restrictions to soil function when its membership value equals 1. The more the membership value deviates from 1, the restriction of the soil biological index to the soil function becomes stronger. The membership values of each soil biological index were obtained by the following equation:

$$\mu(x) = \begin{cases} 1, & x \geq B \\ \dfrac{x-A}{B-A}, & A < x < B \\ 0, & x \leq A, \end{cases}$$

Where, x is the measured value of each soil biological index value, A and B are the lower and upper limits for the threshold values of each index. The weight can be used to determine the level of importance of each soil biological index. The principal component analysis (PCA) is used to identify the attributes most responsible for the variation between the different indexes. A multivariate analysis is separately applied to each of the cement content treatments.

$$w_i = C_i / C$$

Where, w_i is the weight of the i-th index, C_i is the component capacity value of the i-th index, and C is the component capacity value of all indexes. Based on the single index fuzzy evaluation model and analysis of index weight, a multi-index fuzzy comprehensive evaluation model was established in this research.

$$SBAI = \sum_{i=1}^{n} w_i \times \mu(x_i)$$

Where, *SBAI* is the soil biological activity index, $u(x_i)$ is the membership value of the i-th index, and n is the number of index. The *SBAI* is a synthetic index used in evaluating soil biological characteristics. It is the comprehensive reflection of soil enzyme and soil microbial biomass.

Statistical analysis: A one-way analysis of variance (ANOVA) was employed to compare the plant growth and soil properties among the treatments. The least significant difference (LSD) test was used for the mean separation at a significance level of $p<0.05$. All the statistical analyses were conducted using SPSS statistical software package, and all the results were reported as the mean ± SD (standard deviation).

RESULTS

Plant height and plant density: The plant height (PH) and plant density (PD) in different cement content treatments are given in Table 1. The plant height of *Cynodon dactylon* firstly increased and then decreased with cement content in vegetation concrete increase. The maximum plant height was 9.17 cm when the cement content increased to 4%, and then it decreased faster with the increase of cement content. The plant height was only 3.15 cm when the cement content increased to 12%. As the cement content in vegetation concrete increased, the plant height of *Medicago sativa* decreased. The maximum plant height was 10.78 cm when the cement content was 0%, and then it decreased faster from 10.78 cm to 3.17 cm as cement content increased from 0% to 8%. With increasing cement content, similar decline trend was observed in the change of *Cynodon dactylon* and *Medicago sativa* plant density. The reduced ranges of plant density were 50.55% and 54.40%, respectively. The overall growth of the two plants became worse with increasing cement content, especially when cement content exceeded 8%. Comparing the plant growth of the two plants, the descent scopes of plant height and plant density of *Medicago sativa* were even greater.

Soil physico-chemical properties in vegetation concrete: There was a significant difference (p<0.05) between soil physico-chemical properties in the low cement content and the high cement content (Table 2). Under different site conditions, the soil pH value ranged from 7.06 to 9.13 and increased as the cement content in vegetation concrete increased. The soil was neutral when the cement content in vegetation concrete was 0%. When the cement content increased to 12%, the soil became strong alkaline with the pH value of 8.93, 8.9 and 9.13, respectively. The values of SOM and TN decreased with increase in cement content. And as the cement content exceeded 8%, the SOM values at different site conditions decreased drastically from 12.03 $g.kg^{-1}$ to 4.06 $g.kg^{-1}$ (*Cynodon dactylon*), 14.96 $g.kg^{-1}$ to 4.28 $g.kg^{-1}$ (*Medicago sativa*), 12.09 $g.kg^{-1}$ to 3.52 $g.kg^{-1}$ (unplanted sample), respectively. The range of the TN value was 0.71 $g.kg^{-1}$ to 1.52 $g.kg^{-1}$ at the *Cynodon dactylon* sites, 0.77 $g.kg^{-1}$ to 1.47 $g.kg^{-1}$ at the *Medicago sativa* sites and 0.71 $g.kg^{-1}$ to 1.45 $g.kg^{-1}$ at the unplanted sites.

Soil enzyme activities in vegetation concrete: The overall variation of the three enzyme activities for all sites showed a decreasing trend from the low cement content to the high cement content (Figs. 1-3). The data analysis revealed that high cement content in vegetation concrete exhibited a significant affect (p<0.05) on the enzyme activities. The urease activity of the *Cynodon dactylon* site was only 0.18 mg NH_4^+-$Ng^{-1}d^{-1}$ with 10% cement content, compared with the highest urease activity of 1.20 mg NH_4^+-$Ng^{-1}d^{-1}$ with 2% cement content. The highest urease activity of the *Medicago sativa* site was 1.19 mg NH_4^+-$Ng^{-1}d^{-1}$ at 6% cement content, and as cement content increased to 8%, the urease activity decreased drastically to 0.52 mg NH_4^+-$Ng^{-1}d^{-1}$. The urease activities of the unplanted site were lower than the planted sites under seven cement contents. As cement content increased, the invertase activity decreased drastically from 10.29 mg glucose $g^{-1}d^{-1}$ to 0.02 mg glucose $g^{-1}d^{-1}$ for the *Cynodon dactylon* site, 8.34 mg glucose $g^{-1}d^{-1}$ to 0.12 mg glucose $g^{-1}d^{-1}$ for the unplanted site, and 10.72 mg glucose $g^{-1}d^{-1}$ to 1.22 mg glucose $g^{-1}d^{-1}$ for the *Medicago sativa* site. The phosphatase activity of the *Cynodon dactylon* site and the *Medicago sativa* site decreased rapidly when content of cement increased and then the phosphatase activity reached a steady state with high cement content. The range of phosphatase activity was 0.05 mg phenol $g^{-1}d^{-1}$ to 0.18 mg phenol g-1d-1 for the *Cynodon dactylon* site and 0.05 mg phenol $g^{-1}d^{-1}$ to 0.33 mg phenol $g^{-1}d^{-1}$ for the *Medicago sativa* site. The phosphatase activity of the unplanted site varied from 0.03 mg phenol $g^{-1}d^{-1}$ to 0.13 mg phenol $g^{-1}d^{-1}$ and it showed a decreasing trend with increasing cement content.

Soil microbial biomass in vegetation concrete: There were considerable differences in MBC and MBN among the different cement content treatments of the three planted sites (Figs. 4-5). The highest MBC value of the *Cynodon dactylon* site was MBC 579.19 $mg.kg^{-1}$ at 0% cement content, and it decreased to 220.79 $mg.kg^{-1}$ with cement content at 12%. The MBC values of the *Medicago sativa* site and the unplanted site firstly increased and then the values decreased with the increase of cement content. The minimum MBC of the *Medicago sativa* site was only 204.96 $mg.kg^{-1}$ in cement content of 12% while the maximum value of MBC was 584.03 $mg.kg^{-1}$ when cement content was 2%. The minimum MBC of the unplanted site was only 293.71 $mg.kg^{-1}$ in cement content of 10%, while the maximum value of MBC was 525.95 $mg.kg^{-1}$ when cement content was 4%. The result of MBN showed tendency of decreasing with increase of cement content under the three different conditions. As cement content exceeded 8%, the values of MBN decreased drastically from 10.50 $mg.kg^{-1}$ to 3.02 $mg.kg^{-1}$, 13.22 $mg.kg^{-1}$ to 3.33 $mg.kg^{-1}$ and 6.13 $mg.kg^{-1}$ to 2.52 $mg.kg^{-1}$, respectively.

Soil biological activity in vegetation concrete: The membership values of each soil biological index under different cement content treatments are given in Table 3. The performance of each index was able to be evaluated by dimensional normalization. The minimum membership value of each soil biological index usually appeared in the site with high cement content. In order to get the weight of the soil biological indexes, the eigen value, the percent of variance and the cumulative percentage of the principal component in the soil biological index were calculated in Table 4. The principal component analysis showed that the first principal component explained 79.97% of the total variance. The values of component capacity and weights of the soil biological indexes were listed in Table 5 and the values of *SBAI* for the three site conditions are shown in Fig. 6. Under different cement content treatments, the unplanted site had a lower *SABI* value than the *SABI* value of the planted sites, though a similar decreasing tendency of the *SABI* value

Table 1: The changes of plant height (PH) and plant density (PD) in different cement content treatments.

Cement Content	(%)	0	2	4	6	8	10	12
Cynodon dactylon	PH (cm)	8.8±1.5a	8.9±1.1a	9.2±1.3a	6.5±1.2ab	5.7±1.3ab	4.5±1.3b	3.1±0.6b
	PD (/100cm^2)	68.8±18.6a	65.0±6.4a	51.5±8.7ab	49.0±5.0ab	47.5±5.8ab	40.1±6.6b	34.0±8.9b
Medicago sativa	PH (cm)	10.8±2.7a	9.3±2.7a	8.6±2.3a	5.1±3.1b	3.2±1.6b	3.0±1.2b	2.6±0.7b
	PD (/100cm^2)	9.0±1.4a	7.0±1.6ab	7.0±2.2ab	6.0±2.2ab	6.0±1.6b	5.0±1.4b	4.0±1.4b

Note: Values are means±SD (n=3). Different lower letters in the same row indicate significant differences ($p < 0.05$) in different cement content treatments.

Table 2: The changes of soil physico-chemical properties in different cement content treatments.

Cement Content	(%)	0	2	4	6	8	10	12
Cynodon dactylon	pH	7.10±0.20c	7.97±0.38b	8.02±0.21b	8.26±0.59ab	8.59±0.40ab	8.74±0.37a	8.93±0.33a
	SOM(g.kg^{-1})	19.00±0.17a	17.53±0.15b	17.02±0.18b	15.41±0.15c	12.03±0.20d	4.06±0.26e	3.66±0.17be
	TN(g.kg^{-1})	1.52±0.20a	1.50±0.20a	1.43±0.12a	1.33±0.23ab	1.04±0.09b	0.71±0.09c	0.72±0.05c
Medicago sativa	PH	7.07±0.15c	7.77±0.39b	8.33±0.32b	8.73±0.67ab	8.86±0.19a	8.95±0.51a	8.90±0.33a
	SOM(g.kg^{-1})	14.96±0.13a	14.70±0.31a	13.56±0.24b	12.81±0.24c	11.77±0.35d	4.98±0.36e	4.28±0.32e
	TN(g.kg^{-1})	1.46±0.14ab	1.46±0.13ab	1.48±0.04a	1.31±0.04b	1.01±0.14c	0.78±0.09d	0.77±0.08d
Unplanted samples	pH	7.06±0.53c	7.59±0.25c	8.60±0.22b	8.65±0.61ab	8.63±0.16b	9.07±0.54ab	9.13±0.24a
	SOM(g.kg^{-1})	12.09±0.16a	11.37±0.26b	10.87±0.34bc	10.20±0.21c	8.32±0.20d	4.56±0.29e	3.52±0.19f
	TN(g.kg^{-1})	1.45±0.07a	1.40±0.14ab	1.39±0.15ab	1.37±0.15ab	1.21±0.11b	0.79±0.05c	0.71±0.15c

Note: Values are means ± SD (n=3). Different lower letters in the same row indicate significant differences ($p<0.05$)in different cement content treatments; SOM = soil organic matter; TN = soil total nitrogen.

Table 3: The membership values of each index under different cement content treatments.

Cement Content	(%)	0	2	4	6	8	10	12
Cynodon dactylon	Urease	0.81	1	0.94	0.80	0.95	0.09	0.11
	Invertase	0.91	0.96	0.65	0.63	0.54	0.001	0
	Phosphatase	0.49	0.27	0.08	0.08	0.07	0.07	0.07
	MBC	0.99	0.92	0.81	0.68	0.74	0.09	0.04
	MBN	0.95	1	0.97	0.41	0.34	0.03	0.03
Medicago sativa	Urease	0.91	0.62	0.94	0.99	0.39	0.13	0.005
	Invertase	1	0.81	0.56	0.56	0.61	0.15	0.11
	Phosphatase	1	0.76	0.28	0.29	0.07	0.07	0.07
	MBC	0.78	1	0.97	0.96	0.60	0.22	0
	MBN	0.83	0.75	0.67	0.66	0.45	0.04	0.03
Unplanted samples	Urease	0.56	0.43	0.39	0.44	0.10	0	0.02
	Invertase	0.78	0.73	0.42	0.33	0.14	0.01	0.01
	Phosphatase	0.36	0.37	0.35	0.35	0.27	0.07	0
	MBC	0.59	0.83	0.85	0.57	0.57	0.23	0.25
	MBN	0.51	0.50	0.37	0.29	0.16	0.01	0

Note: MBC = soil microbial biomass carbon; MBN = soil microbial biomass nitrogen.

from low to high cement content existed in the three sites. With the 0% cement content, *Cynodon dactylon* achieved a *SBAI* value of 0.87, 0.89 for *Medicago sativa,* and 0.58 for the unplanted site. At 12% cement content, the *SBAI* value of *Cynodon dactylon, Medicago sativa* and the unplanted site decreased to 0.05, 0.04 and 0.06, respectively. And when the cement content exceeded 8%, the *SBAI* values of all the sites had noticeably decreased. The average *SBAI* value of *Cynodon dactylon, Medicago sativa* and the unplanted site were 0.53, 0.54 and 0.35, respectively.

DISCUSSION

Effect of cement content on the soil physico-chemical properties in vegetation concrete: The value of pH directly reflects the amount of hydrogen ions in the soil and represents acid and alkaline feature of soil. It is an important indicator in the course of soil formation and maturity and has obvious influences upon the form of soil nutrient existence, the effectiveness of soil nutrient, the microbial activity and plant growth and development (Zhang 2007). Different soil pH values will cause different soil nutrient avail-

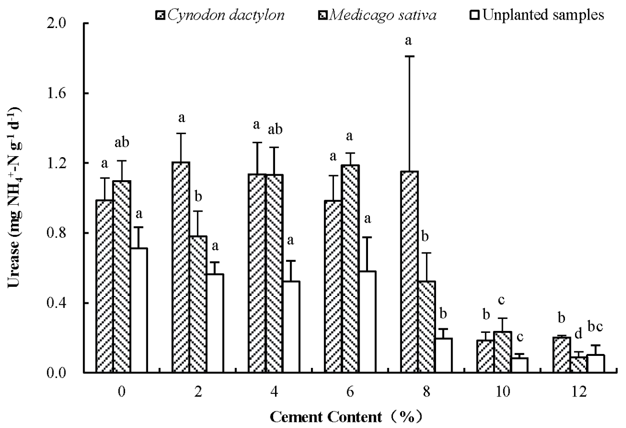

Fig. 1: Changes of urease activity in vegetation concrete at different cement content. Note: Data are mean±SD (n=3). Bars with different lower letters indicate significant differences at $p< 0.05$ in different cement content treatments within each species.

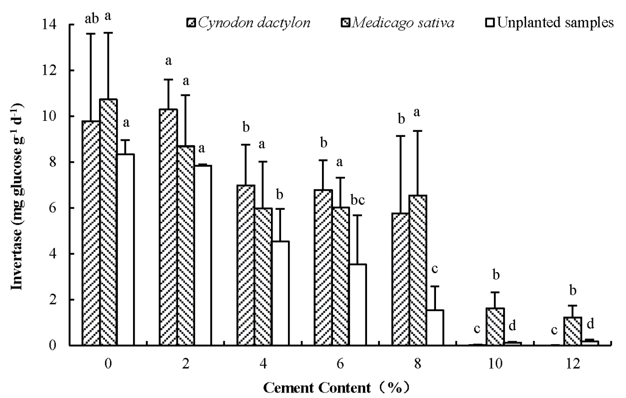

Fig. 2: Changes of invertase activity in vegetation concrete at different cement content. Note: Data are mean±SD (n=3). Bars with different lower letters indicate significant differences at $p< 0.05$ in different cement content treatments within each species.

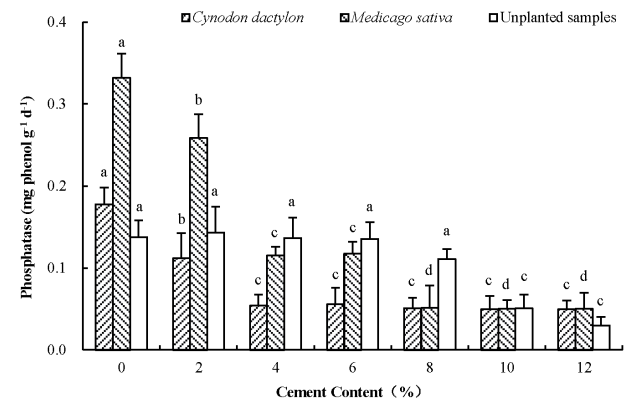

Fig. 3: Changes of phosphatase activity in vegetation concrete at different cement content. Note: Data are mean±SD (n=3). Bars with different lower letters indicate significant differences at $p< 0.05$ in different cement content treatments within each species.

ability and soil fertility (Teng et al. 1999, Yu et al. 2006). Increasing the cement content in vegetation concrete led to higher pH value. This is due to mainly hydration product $Ca(OH)_2$ of cement in vegetation concrete (Xu et al. 2012). The pH value of unplanted site was higher than the pH value of the planted sites when the cement content was high (>8%). This illustrates that plant growth may be of some significance in reducing soil alkalinity. Plant can exude trace amounts of organic acids to neutralize soil alkalinity in the process of growing. On the other hand, increasing vegetation coverage can decrease evaporation from surface and capillarity of soil, then inhibit alkaline move up, with soil moisture rising to surface (Fan 2001).

Physical, chemical and biological characteristics of soil are all having direct and indirect relation with existence of organic matter (Christian et al. 2012). There is a widespread agreement among scientists that loss in soil organic matter can lead to degradation of ecosystem services and loss of ecosystem resilience (Christian et al. 2012). The soil total nitrogen content is an important index to measure nitrogen supply. Change in the soil total nitrogen content mainly depends on relative strength of nitrogen accumulation and decomposition, climate, vegetation, and especially hydrothermal conditions (Bao 2000). The results showed that SOM and TN contents of the three sites obviously decreased when cement content was above 8% (Table 2). When the cement content was lower than 8%, lowest SOM content was always found in the unplanted site. Consequently, the present results suggest that increasing cement content has remarkable implication on organic matter and nitrogen accumulation of soil. Plant is likely to be beneficial for soil organic matter accumulation and soil fertility enhancement, although different plant species with different degrees.

Effect of cement content on the soil enzyme activities in vegetation concrete: Fertilizer supply ability of soil depends on nutrient contents and availability process of soil nutrient and effective extent of soil colloids absorptivity ion. Soil enzyme is a macromolecular biocatalyst with proteinaceous feature including free enzyme, endoenzyme and ectoenzyme (Guan 1986). It is involved in the synthesis and decomposition of humus, the hydrolysis and transformation of organic, dead plants and animals and microbial, and other kinds of oxidation-reduction reactions in soil (Guan 1986). The activity of soil enzyme reflects the intensity and direction of soil biochemical processing and is an important evaluation indicator of soil fertility and soil self-purification capability (Zhang 2007). There is an obvious relationship existed between soil nutrients and soil enzyme activities (Xie et al. 2017). Soil enzyme activities are sensitive indicators of soil quality and may respond to the changes of soil faster than other soil properties (de Medeiros et al. 2017).

As one kind of high specificity hydrolase in soil, urease has ammonification effect (Fisher et al. 2017). The activity of soil urease can be used to reflect nitrogen nutrition level since it can break down the organic material and produce NH_3 and CO_2 by hydrolysis (Guan 1986). And nitrogen is the main ingredient of vegetable protein and one of the three dominant necessary nutrition elements for plant growth (Bao 2000). So increasing the soil urease activity is good for improving nitrogen nutrition level of soil to further improve plant growth. Invertase extensively exists in soil and participates in the process of metabolism directly and reflects the law of soil organic carbon accumulation and decomposition and transformation (Zhang 2007). The soil with strong phosphatase activity has a high content of available phosphorus because the soil phosphatase can promote phosphorus compounds hydrolyzation (Guan 1986). The high cement content in the vegetation concrete significantly affected the soil enzyme activities though the responses in the three sites differ. When content of cement in vegetation concrete was high, the activities of soil urease, invertase and phosphatase decreased to a lower level (Figs. 1-3). This is due mainly to hydration of cement in vegetation concrete (Xu et al. 2012), and therefore, make the vegetation concrete to become strongly alkaline (Table 2). Soil enzymes only have stability within a certain range of pH values. Unsuitable acid or alkaline environment will lead change in enzyme molecule space-conformation, and then affect its catalytic activity (Marzadori et al. 2000, Yang et al. 2009).

Effect of cement content on the soil microbial biomass in vegetation concrete: Soil microbial biomass is the amount of active organism matter per unit volume (Zhang 2007). By participating in decomposition of soil organic matter and production of humus, soil microbial supply dynamics for transformation and cycling of soil nutrients and organic matter, and therefore, play an extremely important role in course of energy flow and nutrient turnover (Post & Kwon 2000). Any change in soil microbial biomass can affect soil nutrient cycling and effectiveness (Ritz & Wheatley 1989). So, soil ecosystems stabilization and health are all intimately connected to soil microbes, and it can reflect change of soil quality situation in time (Lal 2004, Davidson & Janssens 2006, Zhao et al. 2006, Yang et al. 2007). Through the experiment it is discovered that soil microbial biomasses of the three sites showed fluctuation change with increase of cement content (Figs. 4-5). Overall, the highest MBC and MBN values usually occurred at low cement content (<4%). The lower microbial biomass in high cement content vegetation concrete may be due to energy diversion into physiological adaptation necessary to tolerate the strong alkalinity (He et al. 2013). Meanwhile, compared to the unplanted site, vegetation concrete was discovered to have

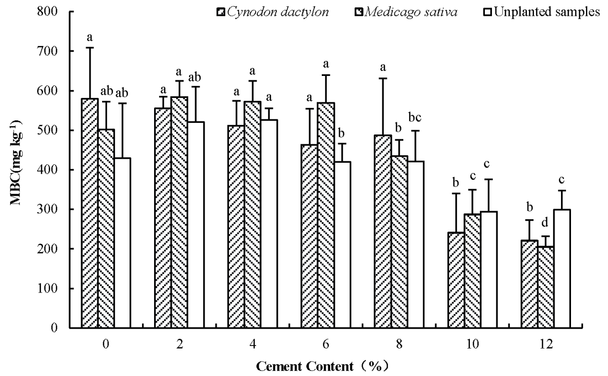

Fig. 4: Changes of MBC in vegetation concrete at different cement content. Note: Data are mean±SD (n=3). Bars with different lower letters indicate significant differences at $p < 0.05$ in different cement content treatments within each species; MBC = soil microbial biomass carbon.

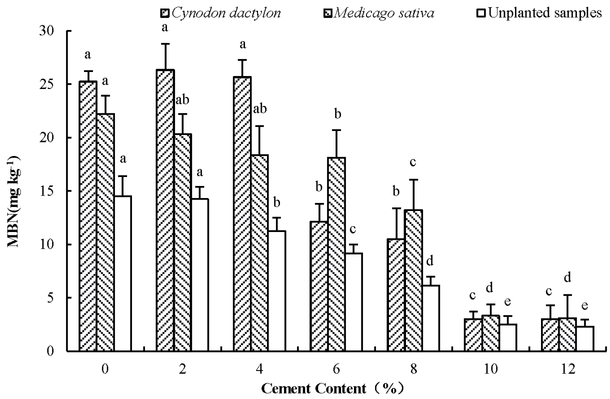

Fig. 5: Changes of MBN in vegetation concrete at different cement content. Note: Data are mean±SD (n=3). Bars with different lower letters indicate significant differences at $p< 0.05$ in different cement content treatments within each species; MBN = soil microbial biomass nitrogen.

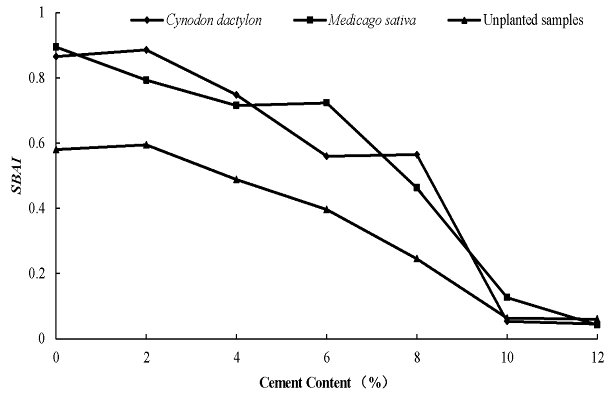

Fig. 6: Changes of *SBAI* in vegetation concrete at different cement content.

Table 4: Cumulative percentage of principal component in the soil biological indexes.

Component number	Eigen values	Percent of variance (%)	Cumulative percentage (%)
1	3.999	79.971	79.971
2	0.641	12.827	92.798
3	0.167	3.348	96.146
4	0.119	2.375	98.521
5	0.074	1.479	100

Table 5: Values of component capacity and weights of the soil biological indexes.

Index	Capacity First component	Weight First component
Urease	0.812	0.203102
Invertase	0.918	0.229615
Phosphatase	0.486	0.121561
MBC	0.866	0.216608
MBN	0.916	0.229115

Note: MBC = soil microbial biomass carbon; MBN = soil microbial biomass nitrogen.

high microbial biomass because of the additional surface for microbial colonization and organic compounds released by the plant roots and litter (Moynahan et al. 2010, He et al. 2013). And in this study, *Cynodon dactylon* was at returning green stage and *Medicago sativa* was at dormancy period, thus the nutrient consumed by plant growth was low. And with the end of winter, the rise of temperature promotes the soil microbial metabolism and more organic matter returns to soil.

To further clarify the effect of cement content on soil microbial growth, the soil MBC/MBN ratio of all the sites were analysed (Fig. 7). The change of the soil MBC/MBN ratio reflected the shifts in soil microbial community structure. When there is high soil MBC/MBN ratio, the greater the proportion of fungi in soil, the lower the proportion of bacteria in soil (Fauci & Dick 1994). Bacteria are the main soil microorganism group and have the greatest capability to decompose soil substance. But the stress resistance of bacteria is poorer than fungi (Tang et al. 2007). Yang et al. (2014) reported that fungi were in an unfavourable position to compete with bacteria when the growing and reproduction environment of microorganisms were improved, the increase of bacterial number would inhibit the growth and development of fungi. The larger the ratio between bacterial number and fungi number, the better the soil quality (Ni et al. 2005). The result showed that the MBC/MBN ratios of the three sites were lower at low cement content (Fig. 7). And for the *Cynodon dactylon* site, the MBC/MBN ratio ranged from 19.93 to 79.66. For the *Medicago sativa* site, it ranged from 22.59 to 86.17. The maximum MBC/MBN ratios appeared at 10% cement content for the two planted sites. The MBC/MBN ratio of the unplanted site ranged from 29.60 to 129.66, and the maximum value of MBC/MBN ratio occurred at 12% cement content. It indicates that the proportion of bacteria in the low cement content vegetation concrete is higher than the proportion of bacteria in the high cement content. The vegetation concrete with low cement content is more environmental friendly to the growth and reproduction of bacteria, and has a higher soil quality. As the content of cement in vegetation concrete increases, the bio-availability of soil carbon and nitrogen decrease, and especially has a more adverse effect on the availability soil nitrogen. It leads to lower content of soil carbon and nitrogen that be assimilated by microorganisms, which is consistent with the decrease observed for the SOM and TN (Table 2). From the discussion above, it can be concluded that soil nitrogen supply is the main restriction factor for soil microbial growth in engineering applications of the vegetation concrete eco-restoration technology. *Medicago sativa* is perennial legume herbage and has a greater capability of nitrogen-fixing than *Cynodon dactylon.* But its nitrogen-fixing capacity by rhizobia is relatively weak at dormancy period, and therefore, needs to take nitrogen from soil. The research of Hannaway & Shuler (1993) has shown that it needs to apply nitrogen fertilizer to increase the yield of *Medicago sativa* when SOM content of soil is below 15 $g.kg^{-1}$. The maximum SOM content of the *Medicago sativa* site was 14.96 $g.kg^{-1}$ (Table 2), thus the *Medicago sativa* site was deficient in nitrogen. This may explain why *Cynodon dactylon* has a better growth status in vegetation concrete in this experiment (Table 1).

Effect of cement content on the soil biological activity in vegetation concrete: It is helpful to further understand interactions that have traditionally been investigated with only physical or chemical method by incorporating biological indicators into the study of biological-chemical-physical processes in soils (Fisher et al. 2017). The minimum membership values of 0 have all occurred in the cement content of 10% or 12% for all measured indexes under different treatments (Table 3). This result suggests that the soil function is strongly limited by the soil biological index with high cement content. The *SBAI* value for the three

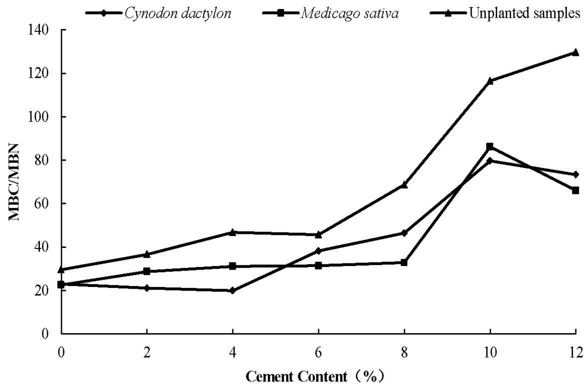

Fig.7: Effect of cement content on soil MBC/MBN ratio in vegetation concrete.

site conditions are used to evaluate how soil enzyme and soil microbial biomass characterized the soil quality change at different content of cement. The analysis showed that the maximum value of *SBAI* appears in low cement content (0%, 2%), and it declined sharply when cement was at 8% content (Fig. 6). The *SBAI* values were lower with high cement contents (10%, 12%). Under the same cement content, the *SBAI* value of the unplanted site was lower than the *Cynodon dactylon* site and the *Medicago sativa* site. In conclusion, these results showed that cement in vegetation concrete significantly influence soil biological activity though the responses in the three site conditions differ, especially when cement content in vegetation concrete exceeded 8%. The soil biological activity can be improved to a certain extent by *Cynodon dactylon* and *Medicago sativa*. Thus, the plant appears to beneficially affect soil biological activity. Compared with the analysis above, the *SBAI* can be used as a synthetic index in evaluating soil biological characteristics and, concomitantly, soil quality. These results provide additional support for evaluation of soil quality by sensitive and rapid indicators, and have instructional significance in determining the appropriate cement content range in the application of vegetation concrete eco-restoration technology.

CONCLUSIONS

To sum up, our research results indicated that addition of cement in vegetation concrete had influence on *Cynodon dactylon* and *Medicago sativa* growth and soil quality. These results suggested that the two plants had some adaptable protection and resistance ability within a certain range of cement content (≤ 8%). And *Cynodon dactylon* was more suitable than *Medicago sativa* for application in the vegetation concrete eco-restoration technology with better growth status. The evidences from this study showed that increasing cement content had significant effect on the soil quality. And when content of cement in vegetation concrete exceeded 8%, it was more detrimental to soil quality with low *SBAI* value. Meanwhile, it can be concluded that plant is beneficial for soil fertility. In consideration of plant growth and soil quality, the appropriate range of cement content in vegetation concrete is 4%-8%. But in slope ecological restoration engineering application, slope stabilization is one of the most important factors which must be considered. For gentle slope (<45°) or stability good slope, the proportion of vegetation concrete is mainly focused on plant growth and soil fertility. Low cement content (4%) might be suggested to reduce engineering cost. And range up to 8% or more cement content is suggested when slope angle ranges from 45° to 85° to ensure slope stability. The research also has provided evidence that nitrogen supply is the main restriction factor in the application of vegetation concrete eco-restoration technology when *Medicago sativa* is selected as pioneer plant. Applying nitrogen fertilizer in the growth prophase of *Medicago sativa* can enhance plant yields. In order to give more valuable suggestion on choosing and planting of species in pioneer species for slope ecological restoration projects, further experimental investigations are needed to carry out on more species.

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