Effects of Different Horticultural Substrates Composition and Depth on Runoff Water Quality

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Abstract. In this research, a new type of roof cultivation substrate with different ratios of six kinds of substrate products and inorganic substrates was laid in a self-made roof model with a thickness of 7.5 cm and 15 cm, and the substrate was sprayed to record the matrix flow production time, the amount of runoff water, etc., then the water quality of the collected runoff was tested and a significant test was conducted. The results showed that with the increase of the depth of the same matrix, the storage capacity of the matrix is stronger. Finally, three more ideal matrix formulations were selected: T222 [V{substrate product (V straw: V cow manure: V lignite = 12:2:4)}: V vermiculite: V fly ash = 2 : 3:3] optimal, followed by T122 [V{substrate product (V straw: V cow manure: V lignite = 12:4:2)}: V vermiculite: V fly ash = 2: 3:3] and T422 [V{Substrates (V Straw: V Cow manure: V peat = 12:2:4)}: V Vermiculite: V fly ash = 2:3:3].

Introduction

In the past three years, more than 360 cities have encountered waterlogging, and "every rain will fall" has become one of the major urban disasters in China. Sponge City has good "elasticity" in adapting to environmental changes and responding to natural disasters. One of the key technologies for the construction of Sponge City is to absorb and accumulate rainwater by laying a certain thickness of horticultural substrate on the city's roofs and garden level. In recent years, roof cultivation techniques have been widely used in developed countries such as Germany, the United States, and Japan. However, there are still some cities that have not yet developed roof cultivation facilities, in China. In addition to the first batch of pilot cities, the subsequent cultivation of urban rooftops is still less than 1%. It can be seen that there is still a great deal of development in roof cultivation in China. Many studies abroad have shown that roof cultivation techniques have great ecological and environmental benefits. For example, roof cultivation techniques can retain rainwater, thereby prolonging the time for surface runoff and reducing the effects of waterlogging. At the same time, plants can absorb CO_2, CH_4 and other greenhouse gases and pollutants in the air to optimize air quality and reduce pollution and the effcet of urban heat island effect. However, there has been controversy over the study of the surface runoff water quality after roof cultivation. The main reason lies in the differences in the formula, depth and daily management of the roof cultivation matrix selected by the researchers.

This study focused on the effects of roof cultivation substrates on surface runoff water quality and water volume. First, six kinds of new horticultural substrates were formulated from six kinds of agricultural and forestry waste matrix products, peat and pastoral soil, vermiculite and fly ash. Based on the simulated rainfall test, the depths of 7.5 cm and 15 cm of the two substrates were designed to analyze the retention capacity of the eight new horticultural substrates at different depths and the pollution degree of runoff water quality, and a more suitable light roof cultivation was selected. Matrix to provide scientific basis for the application and promotion of roof cultivation techniques.

Materials and methods

The experiment was conducted in the glass greenhouse of Beijing University of Agricultural.

Experiment materials

Raw materials included cow dung and corn stalks. Fresh cow dung was purchased from Beijiao farm in Beijing. Corn stalks were taken from Beijing University of Agricultural Experimental Base and crushed to 1 to 2 cm. Additional excipients were as follows: homemade peat was purchased from Fengtai Flower and Wood Center in Beijing; lignite was acquired in suburban coal yard in Beijing, fly ash was acquired from Chengde Luanhe Power Plant.

The basic physical and chemical properties of additional excipients are shown as Table 1.

Tab. 1 Basic physical and chemical properties of additional excipients

Kinds of excipients	pH	EC/($mS\cdot cm^{-1}$)	Total salt/%	TDS/($mg\cdot L^{-1}$)
Lignite	4.85	1.627	0.10	814.0
Peat	4.88	0.261	0.02	130.6
Fly ash	7.76	0.566	0.03	283.0

Experiment design

On the basis of the results of early fermentation test of the research group, the volume ratio of corn straws to cow dung and auxiliary materials was 12:3:3 as a control (lignite as C1, peat as C2), and the total volume were kept constant. Four treatments are shown in Table 2.

Tab. 2 Composting program test

Test	Fermenting component	Volume ratio
T1	corn stalks: cow dung: lignite	12:4:2
T2	corn stalks: cow dung: lignite	12:2:4
T3	corn stalks: cow dung: peat	12:4:2
T4	corn stalks: cow dung: peat	12:2:4
C1	corn stalks: cow dung: lignite	12:3:3
C2	corn stalks: cow dung: peat	12:3:3

The matrix product or matrix is mixed with vermiculite and fly ash, and a self-designed simple roof model is used to load the matrix with different proportions and depths (Table 3), and then use the simple simulation sprinkler irrigation water collecting device to the matrix simulated rainfall of 1.8 mm/min was carried out for 30 min. Finally, the runoff water quality was collected and related pollution indicators were determined.

Tab. 3 Experimental design of simulated irrigation

Test	Matrix product or matrix：Vermiculite：Fly ash（Volume ratio）	Substrate depth/mm
Kind of fermentation	1:1:1	7.5
Product or matrix	2:3:3	15.0

Note: Fermentation product is product of T1-T4, C1 and C2. Matrix is domestic peat or garden soil. The code rule of the simulation irrigation experimental processing is Nxyz, where Nx stands for corresponding compost experimental code, y represents two different ratios of the matrix mixture, and z is two different thicknesses of the matrix.

Experiment equipment

The construction process of a simple simulation sprinkler irrigation water collecting device was as Figure 1. Firstly, a small hole is directly under the sorting box (59*38*34 cm) for collecting runoff water; secondly, a draining board (about 2 cm in thickness) is laid in the sorting box for drainage and to prevent large-grained matrix Drain; the last, a layer of geotextile was covered to prevent the loss of small particles such as sediment.

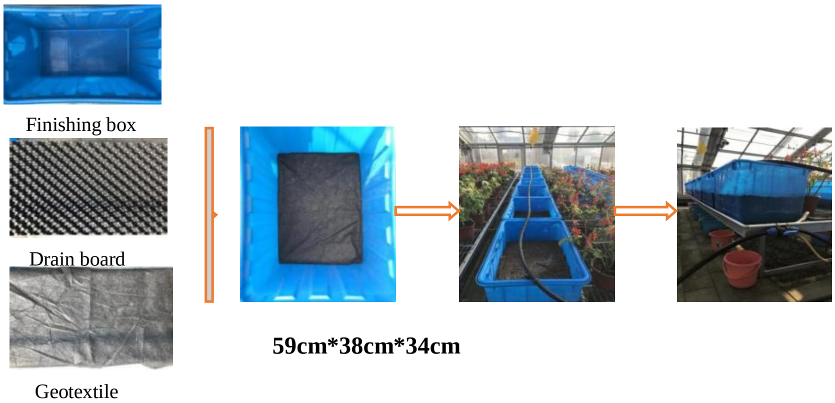

Fig. 1 Simple simulation sprinkler irrigation water collecting device construction process

Measurement indicators and methods

Surface water pollutant indicators: COD, ammonia nitrogen, total phosphorus, SS, pH, EC[1] and other indicators, are measured in accordance with national standards[2].

Tab. 4 Indicators measuring instrument

Indicators	Instrument
Flow time Lag time	Stopwatch
Runoff	Ruler
COD	ET 125 SC COD Rapid Tester
ammonia nitrogen total phosphorus SS	Lianhua Science and Technology 5B-6C Multi-parameter Water Quality Tester
pH	PHS-2F pH meter
EC	DDSJ-308A conductivity meter

Data processing and analysis

This study uses Excel 97-2003 and SPSS 22.0 software for statistical analysis and mapping.

Results and analysis

Water storage capacity of substrate

The time of runoff can reflect water holding ability of the substrate during a period of time when it has been washed with water. In the simulated experiment, formation of runoff from the water-permeable substrate is later, and then the ability of water storage of matrix is better.

The volume of runoff can reflect the drainage of the matrix. The displacement is larger, the ability of the matrix of water retaining is weaker, and the contrary is stronger. It can explain the matrix retention capacity better. The retention rate can intuitively reflect the ability of the substrate to intercept water.

The results showed in table 5 indicated that the runoff time was prolonged, surface runoff became less, and the retention rate of the matrix on runoff was higher with the same kind of matrix deeper. In the mixed substrate formulation with matrix ratio of 1：1：1 volume ratio of vermiculite and fly ash, T112 matrix has the best water storage capacity and is superior to peat, but lower than urea soil; The mixed matrix of the product (V straw: V cow manure: V lignite= 12:3:3) had the best water storage capacity in the mixed matrix formulations and was superior to peat but lower than the pastoral soil.

Tab. 5 Runoff of different experimental treatments in simulated irrigation

Test	Flow time/s	Runoff/mm	Runoff retention rate/%	Average/ %	Detention rate increase/%
T111	832	28	48.1	58.3	20.4
T112	1350	17	68.5		
T211	670	35	35.2	35.2	0.0
T212	668	35	35.2		
C111	327	34	37.0	47.2	20.4
C112	957	23	57.4		
T311	777	32	40.7	50.0	18.6
T312	1308	19	59.3		
T411	585	38	13.0	21.3	16.6
T412	615	47	29.6		
C211	327	34	22.2	25.9	7.4
C212	957	23	29.6		
CK111	515	28	48.1	56.45	16.7
FCK112	1033	19	64.8		
CK211	1045	24	55.6	75.0	38.8
CK212	1734	3	94.4		
T121	913	27	50.0	61.1	22.2
T122	1202	15	72.2		
T221	716	34	37.0	44.45	14.8
T222	930	26	51.9		
C121	788	32	40.7	50.9	20.4
C122	1033	21	61.1		
T321	808	30	44.4	54.6	20.4

T322	927	22	64.8		
T421	807	33	38.9	44.45	11.1
T422	887	27	50.0		
C221	587	38	29.6	41.65	24.1
C222	970	25	53.7		
CK121	867	27	50.0	62.05	24.1
CK122	1290	14	74.1		
CK221	1022	20	63.0	78.7	31.5

In the mixed matrix formulation of the matrix product with the volume ratio of vermiculite and fly ash of 2:3:3, the matrix of T122 treatment had the best water storage capacity in each treatment, but was slightly lower than that of peat; the matrix product (V cow manure: V straw: V lignite= 12:3:3) had the best water storage capacity in the mixed matrix formulations but was slightly lower than that of peat.

Tab. 6 Runoff retention capacity of different matrixes

Matrix ratio	Substrate depth	T1	T2	C1	T3	T4	C2	Peat	pastoral soil
1:1:1	7.5	48.1	35.2	37.0	40.7	13.0	22.2	48.1	55.6
	15	68.5	35.2	57.4	59.3	29.6	29.6	64.8	94.4
Average	-		46.9bc			32.4c		56.45b	75.0a
2:3:3	7.5	50.0	37.0	40.7	44.4	38.9	29.6	50.0	63.0
	15	72.2	51.9	61.1	64.8	50.0	53.7	74.1	94.4
Average	-		52.15bc			46.9c		62.05b	78.7a

Note: the same column data is marked with different lower case letters, indicating significant difference ($P<0.05$).

From Table 6, it can be seen that the retention rate of the matrix to runoff water is higher with the increase of the ratio of the inorganic matrix added to the same kind of substrate product. The retention capacity of T1 and T2-treated matrix on runoff water was stronger than that of T3 and T4-treated matrix, but there was no significant difference between the two at the 0.05 level; both were lower than the retention capacity of the two control matrices, but the retention capacity of the T1 and T2-treated matrix. At 0.05 level the difference with peat was not significant. The reason for this phenomenon may be due to the higher water-holding pores of fly ash in the inorganic matrix. The retention capacity of the matrix increases with the increase of fly ash, and the matrix product is produced by fermentation of straw. High, therefore, the storage capacity of the substrate product is weaker than that of peat and pastoral soil.

Contamination analysis of substrate

As can be seen from Table 7, the matrix product was mixed with vermiculite and fly ash in a 1:1:1 volume ratio mixed matrix formulation. The mean concentrations of COD, ammonia nitrogen, total P, SS, and EC in the surface runoff of the two control matrices were Lower, and in line with the national surface water environment, Class V standards. In terms of COD concentration, the COD concentration of all treated substrates was significantly higher than that of the two controls and the content was excessive. In terms of ammonia nitrogen concentration, ammonia nitrogen content of the remaining substrates met the standard, except T31 and C21 treated substrates, which exceeded the standard, and T11and T21. The ammonia nitrogen content was not significantly different from that of peat moss CK21at 0.05 level. In terms of total P concentration, the total P content of the rest of the treated substrates was in compliance with the exception that the total P content of the treated substrates of T11 and T31 was exceeded. In terms of SS concentration, only the SS content of the substrate treated with T11 and T21 was not significantly different from that of the two controls at the 0.05 level, and the other treatments were significantly higher than the two controls. In terms of pH value, all treatments reached the national surface water environmental quality class V standard, and the pH of field soil CK21was significantly higher than other substrates at the 0.05 level, T11 and T41 The pH of the treated substrate was significantly higher at the 0.05 level than the poke moss CK11. In terms of EC value, except for T11and T21 treatments, EC values of the remaining treated substrates were significantly higher than those of the two controls at a level of 0.05.

Tab. 7 Comparison of water quality parameters of matrix

Text	COD ($mg\cdot L^{-1}$)	ammonia nitrogen ($mg\cdot L^{-1}$)	P total ($mg\cdot L^{-1}$)	SS/($mg\cdot L^{-1}$)	pH	EC/（$ms\cdot cm^{-1}$）
T11	47.50±9.59c*	0.48±0.10d	0.44±0.04b*	6.74±1.63c	7.94±0.03b	2.41±0.27cd
T21	63.75±12.59c*	0.65±0.26d	0.13±0.02d	4.08±0.59c	7.68±0.01d	2.99±0.89c
C11	172.33±34.69b*	1.54±0.09c	0.20±0.01c	50.49±10.33b	7.70±0.03d	4.42±0.79b
T31	240.17±24.55a*	2.02±0.09ab*	0.53±0.12a*	86.95±12.75a	7.87±0.13bc	6.18±0.84a
T41	157.00±21.39b*	1.88±0.08b	0.38±0.08b	41.54±6.22b	7.94±0.03b	4.30±0.30b
C21	181.00±35.86b*	2.12±0.24a*	0.20±0.04c	82.80±12.45a	7.78±0.22bcd	4.91±1.24b
CK11	16.50±2.22d	0.53±0.02d	0.01±0.00e	5.27±0.35c	7.74±0.18cd	1.94±0.30d
CK21	18.83±1.21d	0.08±0.02e	-	2.17±0.79c	8.27±0.08a	2.31±0.27cd
T12	87.17±6.07c*	0.64±0.18bc	0.26±0.22a	10.08±4.50d	7.83±0.10b	3.81±1.01bc
T22	11.83±5.43d	0.38±0.15c	0.03±0.02b	2.66±0.86e	7.64±0.19c	2.97±0.23cde
C12	113.83±4.22c*	1.27±0.35a	0.32±0.30a	24.84±6.22c	7.56±0.03cd	4.79±1.00b
T32	158.83±21.79b*	1.45±0.14a	0.37±0.13a	54.35±0.81a	7.97±0.03a	3.98±0.40bc
T42	92.00±20.61c*	0.80±0.07b	0.22±0.02a	26.12±1.18c	8.03±0.07a	3.12±0.40cd
C22	267.67±87.91a*	1.19±0.27a	0.31±0.17a	35.10±10.04b	7.48±0.03d	5.78±1.35a
CK12	22.83±5.21d	0.53±0.29bc	0.05±0.04b	4.26±1.33de	7.65±0.13c	2.06±0.29e
CK22	17.50±3.45d	0.59±0.07bc	0.04±0.03b	5.66±2.72de	7.94±0.09ab	2.24±0.41de

Text water	0	0.01	0.15	0.93	8.53	0.30
National V standard	≤40	≤2	≤0.4	-	6-9	-

Note: the same column data is marked with different lower case letters, indicating significant difference ($P < 0.05$)."*" indicates that the water quality parameters are beyond the national standards for the quality of the surface water environment of the state V.

It can be seen from Table 7 that the concentration of COD, ammonia nitrogen, total P, SS, and EC in the surface runoff of the two control substrates are the average values of the matrix product and the mixed matrix formulation of vermiculite and fly ash in a volume ratio of 2:3:3. Lower, and in line with the national surface water environment, Class V standards. In terms of COD concentration, except for T22 treatment, the COD concentrations of the other treated substrates were significantly higher than those of the two controls, and the levels exceeded. In the ammonia nitrogen concentration, the ammonia nitrogen content of all treated substrates met the standard, and the ammonia nitrogen content of T12, T22 and T42 treatments was not significantly different from that of the two controls at the 0.05 level. In the total P concentration, the total P content of all treated substrates met the standard, and the total P content of the T22 treatment was not significantly different from that of the two controls at the 0.05 level. In terms of SS concentration, only the SS content of the substrate treated withT12 and T22 was not significantly different from that of the two controls at the 0.05 level, and the other treatments were significantly higher than the two controls. In terms of pH value, all treatments reached the national surface water environmental quality class V standard, and the pH values of the T32 and T42 treatment substrates were significantly higher than the 0.05% of the CK12. However, the difference between CK22 was not significant, and the pH of the T12 treatment substrate was significantly higher than that of the grass carbon CK12 at the 0.05 level. In terms of EC value, except for T22 and T42 treatments, EC values of the remaining treatment matrix were significantly higher than the two controls at the 0.05 level.

Conclusion

(1) The retention rate of the matrix to runoff water increases with the increase of the proportion of the inorganic substrate added to the same kind of substrate product. And the composite matrix formed by the ratio of the browning coal as the auxiliary material of matrix material to the retention capacity of run-off water is stronger than the compound matrix formed by the ratio of the matrix material of the auxiliaries of peat. The highest retention rate of T122 matrix was 72.2%.

(2) The composite matrix obtained with different ratios of substrate product and inorgani matrix is slightly less than the peat and pastoral soil in terms of water storage capacity, in which the substrate product (V lignite: V cow dung: V straw = The ratio of 1:2:6) to the inorganic matrix gives the matrix the best water storage capacity in the formulation of the mixed matrix and is comparable to that of peat.

(3) The COD in the runoff of the roof cultivation substrate obtained with the different ratios of the substrate product and the inorganic substrate is in addition to the FH2w treatment substrate, and the rest of the treatment substrates exceed the national surface water environment quality class V standard; the substrate product and vermiculite, powder In the 1:1:1 volume ratio of fly ash mixed matrix formulation, ammonia nitrogen and P total pH of the runoff water of the T21, C11and T41

substrates met the standard; In the mixed matrix formulation with the volume ratio of vermiculite and fly ash of 2:3:3, the ammonia nitrogen, P total pH of the runoff water quality of all treated substrates met the standard. The SS concentration in runoff water quality of T12 and T22 substrates was not significantly different from that of peat and pasture soil. T12, T32 and T42 substrates had significantly higher pH values than peat and could better neutralize acid rain in nature. The EC values of runoff water quality of T11, T22 and T42 treated substrates were not significantly different from those of peat and arable soil.

Therefore, the comprehensive indicators found that with the increase of the depth of the same matrix, the storage capacity of the matrix is stronger. Finally, three more ideal matrix formulations were selected: T222 [V{substrate product (V lignite: V cow manure: V straw = 2:1:6)}: V vermiculite: V fly ash = 2 : 3:3] optimal, followed by T122 [V{substrate product (V lignite: V cow manure: V straw = 1:2:6)}: V vermiculite: V fly ash = 2: 3:3] and T422 [V{Substrates (V peat: V Cow manure: V Stalk = 2:1:6)}: V Vermiculite: V fly ash = 2:3:3].

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