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Grape Cultivation Delays Soil Desertification and Produces Economic Benefits in the Karst Region

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Additional index words: *Vitis quinquangularis;* response surface methodology; water and fertilizer; Karst Area

Abstract

The Southern China karst area that represented the most typical tropical-subtropical karst in the world showed serious desertification. The grape cultivar 'Yeniang No.2' was a variant with high drought resistance that we selected from *Vitis quinquangularis*. 'Yeniang No. 2' was planted in containers with desertified soil of a karst region, and treated with a range of levels of irrigation, nitrogen (N), phosphorous (P) and potassium (K). After four years, soil pH decreased, soil organic matter and soil available N, P, and K increased. Therefore, local farmers could plant "Yeniang No. 2" at the foot of karst mountains or on lower elevation mountains to improve the environment and earn income. The highest fruit yield was 73.64 kg/vine when P=2.674 g/vine, and K=2.15 g/vine. The reasonable combination could significantly increase soil fertility in the karst area and save money for local farmers.

The South China karst is one of the best examples of a typical tropical-subtropical karst in the world. This area is world-renown for its natural heritage represented by Stone Forest, Libo and Wulong, covering an area of about 540,000 km^2. This area was home to more than 100 million people and 48 ethnic minorities (Xiong et al, 2011), and the poor population was relatively concentrated. The available cultivated land in this region is scarce because of serious desertification, prominent human-land conflicts, vegetation destruction, soil erosion, gradual exposure of rocks, declining or even loss of land productivity, and the surface showed evolutionary processes or results similar to landscape desertification (LeGrand, 1973; Xiong et al, 2011; Zheng, 2008; Zhang et al, 2010). The Chinese government had increased its governance after the 21st century (Xiong et al, 2009; Wang et al, 2003; Yuan, 2008). Soil erosion was the core problem of rocky desertification, and it had serious consequences when soil fertility was reduced. At present, desertification control requires ecological restoration as the core principle, and selection of plants with both ecological and economic benefits to maintain soil and water.

Vitis quinquangularis is native to China and is dioecious. It grows in the forests and shrubs in the wild at altitudes of 100 to 3000m in vast areas of Central China and South China, such as Hubei, Hunan, Jiangxi, Guangxi, Guangdong, Yunnan and Guizhou provinces (Zou, 2008). For a long time, local farmers used the pulp of *Vitis quinquangularis* for wine making. The main cultivation areas were Guangxi and Hubei, and farmers used tissue culture plants (Zou, 2008). Four female flower cultivars, "Shuiyuan No.1", "Yeniang No.1", "Yeniang No.3" and "Yeniang No.4", were selected (Zou et al, 2012). "Yeniang No. 2" was the first bisexual flower cultivar with high drought resistance discovered by the author after more than 10 years of resource collection in Guangxi (Zou et al, 2013). Now, "Yeniang No. 2" has been used as a poverty-relief tree species in the karst area of Guangxi Province. Even in the cracks of stones, the yield per plant is about 50kg. The cultivar is now being pushed to the karst

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Table 1. Water and fertilizer levels (g/plant per irrigation time) from which 30 treatment combinations were selected.

Factor	-2	-1	0	1	2
N(g/plant)	0	10	20	30	40
P(g/plant)	0	8.8	17.6	26.4	35.2
K(g/plant)	0	12.45	24.9	37.35	49.8
Water(L/plant)	25.12	37.68	50.24	62.80	75.36

areas of Guizhou and Yunnan provinces.

In view of the current situation of karst rocky desertification and the poor living conditions of local people, the aim of this study was to find a cash crop that can alleviate karst desertification and increase the income of local farmers. 'Yeniang No.2' grapes were grown in the soil of karst desertification with varying levels of fertilizer and water to evaluate plant growth and soil nutrient concentration. The results of the study could provide justification for a possible ecological and economic crop for the local karst desertification status and the status of farmers' poverty.

Materials and Methods

The experiment used a quadratic universal rotation combination design (Table 1) with 30 runs (Song et al, 2018; Cai et al, 2017). The design optimization reduces the number and cost of expensive complete factorial experiments (30 instead of 5*5*5*5=625 treatment combinations) to construct response surfaces. The technique is most commonly used in engineering to maximize the production of a special substance by optimization of operational factors (Raissi & Farsani, 2009). Plants were obtained from Guangxi Plant Tissue Culture Seedling Co., Ltd. Ninety-day-old tissue culture plants, about 15 cm tall with eight leaves were planted into the 113 L pots with soil from rocky desertified land from Luocheng County, Guangxi (Fig. 1). After two months the vines were headed at 20 cm and were supported by fastening to poles about 2.0 m above soil level.

Treatments consisted of combinations of five equal distant levels (-1 -2 0, 1, 2) of irrigation, N (urea), P (P_2O_5), and K (K_2O) (Table 1). Table 2 shows the 30 combinations of the four factors with nine vines per treatment (270 total plants, 90 plants were used for the vegetative stage experiment and 180 plants were used for the fruit stage experiment.). The experiment was conducted for four years and each year plants were irrigated on the 1st and 15th day of each month from May to Sept. and on the 1st of Oct. and Nov. From Dec. to April plants were irrigated enough to keep the soil moist. Irrigation levels included 25.1, 37.7, 50.2, 62.8 and 75.4 L every two weeks. Fertilizer was placed in two 5-cm deep holes on opposite sides of each plant on the 1st day of each month from

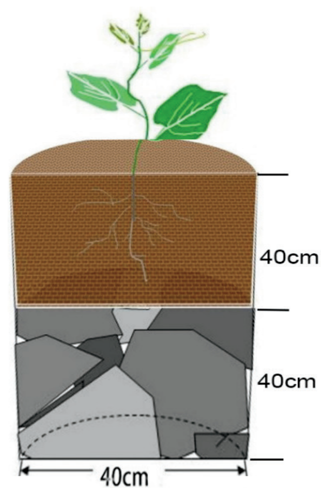

Fig. 1. Diagram of plant growing in a pot with rock desertification (grey) below a soil layer (brown).

Table 2. Thirty combinations (runs) of water and fertilizer levels using universal rotation combination design.

Run	N(g/plant)	P(g/plant)	K(g/plant)	Water(L/plant)
1	30	8.8	37.35	62.80
2	10	26.4	12.45	62.80
3	10	8.8	37.35	62.80
4	20	17.6	49.8	50.24
5	30	26.4	12.45	62.80
6	30	8.8	37.35	37.68
7	20	17.6	24.9	50.24
8	20	17.6	0	50.24
9	20	35.2	24.9	50.24
10	10	8.8	12.45	37.68
11	10	8.8	37.35	37.68
12	10	26.4	37.35	37.68
13	20	17.6	24.9	50.24
14	10	26.4	37.35	62.80
15	30	26.4	37.35	37.68
16	20	17.6	24.9	50.24
17	30	26.4	37.35	62.80
18	0	17.6	24.9	50.24
19	40	17.6	24.9	50.24
20	10	26.4	12.45	37.68
21	30	26.4	12.45	37.68
22	20	17.6	24.9	25.12
23	20	0	24.9	50.24
24	10	8.8	12.45	62.80
25	20	17.6	24.9	75.36
26	20	17.6	24.9	50.24
27	20	17.6	24.9	50.24
28	30	8.8	12.45	37.68
29	30	8.8	12.45	62.80
30	20	17.6	24.9	50.24

May to Sept. Plants were fertilized with one of the 15 combinations of N (0, 10, 20, 30, or 40 g/pot), P (0, 20, 40, 60, or 80 g/pot) and K (0, 15, 30, 45, or 60 g/pot) plus one of the irrigation levels. Each month the fertilizer amount was 1/5 of the total design volume.

The first year (90 plants, 30 runs, repeated 3 times) was the vegetative stage of the grapes, and we measured the growth traits. Number of long roots, number of short roots, root fresh weight, root length, root diameter, main vine length, main vine fresh weight and dry weight, main vine diameter, leaf N, P, K concentrations, petiole fresh and dry weight, leaf fresh and dry weight and water potential were measured on 30th Nov. of the first year.

The third and fourth years (180 plants, 30 runs, repeated 6 times) were the fruiting period of the grapes (the fruits of second year was less and unstable). Yield was recorded on 30th Aug. in the third- and fourth-years. Soil pH, and soil elements were measured on 5th Sept. of the fourth year after the final irrigation on 1st Sept.

To determine whether growing 'Yeniang No.2' without fertilization improved the soil, two additional treatments were included: CK0 (no 'Yeniang No.2' plants) and CK1 (cultivated with 'Yeniang No.2', 9 plants). The two additional treatments were both irrigated with only 50.2 L water every two weeks (400 mm, it is close to the average monthly rainfall in Guangxi) with no fertilizer.

To compare non-planted soil and soil planted with grapes, data were analyzed as a one-way ANOVA with SPSS 22.0 to determine if differences existed for each of the physical and chemical soil properties.

Above-ground (all leaves, all petioles and main vine) and below-ground biomass (all roots) for each plant was placed in an oven at 105 °C for 1 h, and then weighed for dry weight.

About 500 g of soil with no roots about 4 cm below the surface layer and about 15 cm from the main vine, was collected for analysis of physical and chemical properties using methods described by Zhang and Gong (2012): pH (pHS-3C pH meter, water/soil=25 mL/10 g), available N (alkali solution diffusion method), available P ($NaHCO_3$ extraction method), available K (NH_4OAc leaching, flame photometric determination), organic matter (550°C LOI method), water content (Drying 24 h and weighing).

Leaf water potential (ψ) was measured using a PSYPRO dew point water potential meter, between 7:00 HR and 20:00 HR, and data were recorded once every 2 h (Shackel, 1984).

Model selection, regression equations, lack of fit, and P-values of various factors were obtained using Design-Expert 11. All variables were included in the original model and we performed a manual backward elimination until there were only significant variables in the model. First, we deleted the variable with the largest P-value and reran the model. Then, again deleted the variable with highest p-value and repeated this until only significant variables remained in the model and regression equation. In this experiment there were many response variables and we used Design-Expert software to conduct the desirability function approach to multiple response optimization in which several responses are optimized simultaneously. (Derringer & Suich, 1980; Candioti et al., 2014). This technique allowed us to identify the optimum condition, or the levels of the treatment variables, for grapevine growth and yield.

Results

Changes in soil composition. There was a significant difference in soil water and organic matter between the soil in which the plant was cultivated and the soil in which no

Table 3. The changes in soil composition with and without growing grapes after four years.

Characteristic	Initial value	CK0 (No plant for 4 years)	CK1 (With a plant for 4 years)
Soil pH	7.92±0.08A	7.96±0.06A ^{z}	7.87±0.04A
Soil available N (mg/kg)	132.49±2.10A	121.85±3.76B	123.21±4.22B
Soil available P (mg/kg)	52.02±3.04A	40.35±1.67B	39.78±3.02B
Soil available K (mg/kg)	378±10.06A	319.50±11.36B	325.62±16.38B
Soil Water (%)	7.46±0.18A	5.57±0.27B	7.37±0.35A
Organic matter (%)	5.91±0.13A	4.16±0.33B	5.96±0.24A

^{z}Values in rows followed by common letters do not differ at the 5% level of signficance, by analysis of variance.

plant was cultivated (P<0.05), but pH, and soil available N, P and K were not influenced by the presence of grape plants (Table 3).

Regression equations of soil pH was suitable for 2FI model (2 factor interaction) (Table 4). The lack of fit was not significant (P>0.05) (Table 4), indicating that a more complex model was not needed. For pH, the P-value for N, K and N x K was < 0.05 (Table 5), indicating soil pH was influenced by the combination of the two variables.

Soil available N, P and K were linearly related to the amount of those elements that were applied (Table 4). The lack of fit was also not significant. N, P and K had a significant effect on soil available N, P and K respectively (P <0.05) (Table 5).

Changes in vegetative and reproductive growth. The number of long roots increased in a quadratic manner as water was increased (Table 4), whereas the number of short roots was influenced by the interaction of N x P

Table 4. Regression models showing the response of various soil composition and aspects of grapevine growth to fertilizer and water treatments, along wiht P- values for lack of fit and R^2 and preicted R^2 values.

Regression equation	P-value for lack of fit	R^2	Predicted R^2
Soil pH=7.97517-0.035917N-0.032129K+0.001471N×K	0.7191	0.3219	0.1454[z]
Soil water (%) =7.54467	0.7651	0.0000	-0.0702
Organic matter (%) =6.06667	0.8318	0.0000	-0.0702
Soil available N (mg/kg) =131.91667+0.791667N	0.396	0.2716	0.1519
Soil available P (mg/kg) =46.38333+1.8892P	0.1171	0.1738	0.0299
Soil available K(mg/kg) =318.45+7.01807K	0.5695	0.3555	0.2535
Long root number=9.82407-0.170662Water+0.002216Water^2	0.75	0.3738	0.2614
Short root number=1.85833-0.05N-0.06471P+0.003433N×P	0.3501	0.2023	-0.0960
Root length (mm) =59.72222+0.637496Water	0.5071	0.2577	0.1536
Root diameter (mm) =1.79538+0.013067N+0.017605Water	0.3102	0.4718	0.3389
Root fresh weight (g) =-15.85889+1.4836Water	0.5169	0.7820	0.7487
Root dry weight (g) =-9.44339+0.669387Water	0.8703	0.7985	0.7725
Main vine length (cm) =112.72222+0.965366Water	0.4603	0.2951	0.1896
Main vine diameter (mm) =5.86106-0.042677P-0.044601K+0.002059P×K	0.1015	0.2693	-0.0194
Main vine fresh weight (g) =-30.31596+1.84077Water	0.1502	0.7377	0.6929
Main vine dry weight (g) =-5.23083+0.542385Water	0.8209	0.6298	0.5907
Leaves N (%) =3.87333-0.065287Water+0.000526Water^2	0.4788	0.4533	0.2943
Leaves P (%) =1.03125-0.049264Water+0.000849Water^2-0.00000478411Water^3	0.3348	0.7266	0.4913
Leaves K (%) =21.44861-0.940574Water+0.016481Water^2-0.000093Water^3	0.1701	0.5387	-0.1483
Petiole fresh weight (g) =-2.65094+0.121627Water	0.536	0.5336	0.4662
Petiole dry weight (g) =-0.559867+0.026011Water	0.6325	0.4311	0.3488
Leaf fresh weight (g) =-21.98522-0.379542N+1.27118Water	0.7741	0.7869	0.7458
Leaf dry weight (g) =-3.841-0.232306N+0.430379Water	0.6118	0.5380	0.4490
Water potential (MPa) =17.65583+0.068125N-0.133857Water	0.5365	0.5386	0.4356
Yield (kg) =79.79699-1.41332P-1.26974K+0.060357P×K	0.8795	0.2354	-0.0278

[Z] Predicted R^2 = 1-(PRESS/total sum of squares) and is a measure of how well a regression model makes predictions.

Table 5. P-values of independent variables in Table 4 that had significant effects on soil composition and grape vine growth.

	p value of significant variables		
Soil pH	0.002(N)	0.0025(K)	0.0021(N×K)
Soil water			
Organic matter			
Soil available N	0.0031(N)		
Soil available P	0.0219(P)		
Soil available K	0.0005(K)		
Long root number	0.2359(Water)	0.0522($Water^2$)	
Short root number	0.0261(N)	0.0258(P)	0.0269(N×P)
Root length	0.0042(Water)		
Root diameter	0.0189(N)	0.0002(Water)	
Root fresh weight	< 0.0001(Water)		
Root dry weight	< 0.0001(Water)		
Main vine length	0.0019(Water)		
Main vine diameter	0.0164(P)	0.0184(K)	0.0175(P×K)
Main vine fresh weight	< 0.0001(Water)		
Main vine dry weight	< 0.0001(Water)		
Leaves N	0.0033(Water)	0.025($Water^2$)	
Leaves P	< 0.0001(Water)	0.0003($Water^2$)	0.0027($Water^3$)
Leaves K	0.0003(Water)	0.0032($Water^2$)	0.0162($Water^3$)
Petiole fresh weight	< 0.0001(Water)		
Petiole dry weight	< 0.0001(Water)		
Leaf fresh weight	0.0288(N)	< 0.0001(Water)	
Leaf dry weight	0.0351(N)	< 0.0001(Water)	
Water potential	0.0444(N)	< 0.0001(Water)	
Yield	0.0174(P)	0.0186(K)	0.0178(P×K)

(Tables 4 and 5). Root length, root fresh weight and root dry weight increased linearly with increasing water and the lack of fit was not significant (Table 4).

Root diameter increased linearly with increasing N and water (Tables 4 and 5).

Vine length, fresh weight and dry weight increased linearly with increasing water and vine dimeter was influenced by the interaction of water and K (Tables 4 and 5).

Leaf N and petiole fresh weight and dry weight were linearly related to water, whereas leaf p and K were related to water in a cubic manner. Leaf fresh weight and dry weight and water potential were related to N and water in a linear manner (Tables 4 and 5). Fruit yield was influenced by the interact in of P x K.

Optimization of fertilizer and water. According to the regression equation, the maximum or minimum value of the dependent variable within the concentration range of the applied water and fertilizer was calculated (pH was a minimum value, and others were maximum values). The results are shown in Table 6. When considering only reducing the pH of the soil, it was recommended that the amount of water and fertilizer applied be

Table 6. Predicted maximum values of the dependent variables and the quantities of the corresponding significant independent variables required to produce the maximum values.

Extreme dependent variables	Corresponding independent variables
Soil pH_{min}=6.38	N=0, K=49.8
Soil water=7.54	
Organic matter=6.07	
Soil available N_{max}=163.58	N=40
Soil available P_{max}=112.88	P=35.2
Soil available K_{max}=667.95	K=49.8
Long root $number_{max}$=9.55	Water=75.36
Short root $number_{max}$=2.39	N=39.91, P=34.89
Root $length_{max}$=107.76	Water=75.36
Root $diameter_{max}$=3.64	N=40, Water=75.36
Root fresh $weight_{max}$=95.95	Water=75.36
Root dry $weight_{max}$=41.00	Water=75.36
Main vine $length_{max}$=185.47	Water=75.36
Main vine $diameter_{max}$=5.86	P=0, K=0
Main vine fresh $weight_{max}$=108.40	Water=75.36
Main vine dry $weight_{max}$=35.64	Water=75.36
Leaves N_{max}=2.565	Water=25.12
Leaves P_{max}=0.254	Water=25.12
Leaves K_{max}=6.739	Water=25.12
Petiole fresh $weight_{max}$=6.51	Water=75.36
Petiole dry $weight_{max}$=1.40	Water=75.36
Leaf fresh $weight_{max}$=67.73	N=14.48, Water=74.43
Leaf dry $weight_{max}$=28.59	N=0, Water=75.36
Water $potential_{max}$=17.02	N=40, Water=25.12
$Yield_{max}$=73.64	P=2.674, K=2.15

N = 0, K = 49.8. When only the yield was considered, the recommended amount of water and fertilizer applied was P = 2.674, K = 2.15. If the plant body was considered for application, the recommended amount of water and fertilizer was shown in Table 6.

Discussion and Conclusions

Improvement of soil fertility. Soil erosion was one of the important manifestations of regional ecological environmental degradation. Soil deterioration results in poor plant growth in karst areas, and plants may perform poorly due to lack of adequate water and nutrients, which in turn leads to more serious soil erosion. This seemed to make a continuous cycle. However, by providing water and fertilizer to soils in karst areas, we could increase plant growth and promote soil and water conservation, which in turn further enhances the growth of the plants, so that this cycle could be reversed to form a benign cycle. Soil available N, P, K, organic matter and water content were important indicators for assessing the degree of soil desertification in karst area (Liu et al, 2005). “Yeniang No.2” reduced the loss of soil water and organic matter in desertified soil under conditions of only irrigation (Table 3). When grapevines were fertilization and irrigated, soil pH and available N, P and K were significantly improved (Table 4) The optimum values of added N, P, and K for improving the soil N, P, and K levels were 40 g, 35.2 g, and 49.8g, respectively and irrigation with 75.4 L of water was associated with maximum plant growth (Table 6).

Increase in plant growth and fruit yield. Water was an important environmental factor in the karst area and had a very significant effect on promoting plant growth in the karst region (Wang et al, 2003). The results of this study showed that in the vegetative stage, long root number, root length, root diameter, root fresh weight, root dry weight, main vine length, main vine fresh and dry weight, leaf N, leaf P, leaf K, petiole fresh weight and dry weight, leaf fresh and dry weight and water potential were positively related to the amount of water applied (Table 4, 5). N was important for plant growth vegetative growth (Li et al, 2016). Root diameter and water potential was positively related to the amount of N applied (Table 6, 7, 8). P and K had a significant effect on fruit yield (Table 4, 9). This was similar to other plants such as wheat and corn in during reproductive growth (Zhang et al, 2008; Jiang et al, 2011).

In summary, “Yeniang No.2” delayed the desertification process in the karst region, reduced soil pH and prevented the loss of soil organic matter. If the water and fertilizer were applied, the available N, P, and K concentration of the soil could also be increased. In the vegetative stage of “Yeniang No.2” in karst area, the effect of water was greater than that of N, and in the fruit stage yield was not related to the amount of water that was applied, but was mainly affected by P and K and their interaction.

The soil water retention capacity in the karst area is low. We found that the soil will be dry after 1-2 days of watering. Therefore, we believe that the irrigation takes effect in 1-2 days after watering, but has little affect for the remaining 13 days (soil water content was maintained at 7.54%, Table 4). Due to the large amount of water required during the fruiting period, if we want the amount of irrigation to significantly affect the fruit yield, it may require more frequent watering, such as the wine grape in Rocky mountains once a week in Mesa and Delta counties (Hamman & Dami, 2000), instead of increasing the amount of irrigation.

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About The Cover

There are more than 300 banana cultivars and they are classified according to their genomic groups and composition. Three banana fruit genotypes are shown on the front cover. Top Cluster = ripe 'Burro' is a starch cultivar used raw or for cooking ; Right Cluster = mature-green 'Cavendish' is the most common cultivar sold commercially; Bottom Cluster = ripe 'Dwarf Cuban Red' is an excellent desert banana with good taste; and Left Cluster = ripe 'Cavendish'.