# Effects of nano carbon on soil erosion and nutrient loss in a semi-arid loess region of Northwestern China

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**Abstract:** Since 2005, the application of nano carbon (NC) in agriculture and environmental remediation has received considerable attention with most of the research focusing on plant growth and heavy metal absorption. However, little is known about the potential effects of NC on soil erosion and nutrient loss. In this study, rainfall simulation tests were conducted on a soil plot (1 m × 1 m, located in a semi-arid loess region of northwestern China), in which a mixture (5-cm below the soil surface) of NC (0, 0.1%, 0.5%, 0.7% and 1.0% on a mass base) and sandy soil (same as the one in the plot) was embedded as three bands (5 cm wide, 1 m long and 5 cm thick) at the three positions (top, middle and bottom of the plot), respectively. Before the rainfall simulation test, a mixed solution of potassium bromide (1.0 mol/L KBr), potassium nitrate (1.0 mol/L $KNO_3$), monopotassium phosphate (1.0 mol/L $KH_2PQ_4$) was sprayed on the soil surface. Results showed that the sandy soil on the Loess Plateau with 0.7% NC addition (36.47 kg/hm$^2$ on a mass basis) could improve soil water runoff, sediment yield, and nutrient loss in the semi-arid loess region of northwestern China, in addition to preventing soil water from deep percolation. Therefore, NC may have a great potential in soil erosion control on the Loess Plateau of China.

**Keywords:** nano carbon, soil erosion, rainfall simulation tests, runoff, sediment, nutrient loss, semi-arid loess region

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## 1 Introduction

The semi-arid loess region of northwestern China is a transitional zone between the southeastern humid monsoon climate and the northwestern continental dry climate; it has a high soil erosion (1000-15 000 t/km$^2$) and severe nutrient loss due to low vegetation coverage[1,2]. In order to control serious soil erosion and nutrient loss, a great effort has been made since the end of 1950s[3]. Up to now, about 24% of the worst areas have been controlled, and the vegetation coverage on the Loess Plateau has been increased from 31.6% in 1999 to 59.6% in 2013[4-6]. However, due to the thick but loose soil profile, the poor structure stability is a serious problem. The soil and nutrients will easily lose with stormwater runoff, resulting in aggregated problems related to soil and water conservation.

Since the 1990s, different kinds of soil amendment, such as polyacrlamides (PAM) and biochar (or black carbon) have been applied to the soil on the Loess Plateau for controlling soil erosion and nutrient loss[7,8]. PAM was used to improve soil physical properties and protect soils from erosion. However, the chemical characteristic of PAM and its non-improvement in soil organic carbon are still serious problems to overcome. Recently, biochar has been widely used as an amendment because of its many beneficial impacts on soil quality and soil field capacity[9,10]. However, the applied amount is huge-always in tons per hectare, together with its moveable with the runoff, making biochar's use in the fields be unpractical.

Recently, nano carbon (NC) has been applied to agriculture and environmental remediation[3,11]. Usually, NC is made from residual biomass materials (e.g., crop residues and stocks) via a slow thermochemical pyrolysis process. As a carbon-rich material with a diameter in the nanometer range and a large specific surface area, NC can be bonded at the molecular level in different ways to achieve unique properties. NC has been used for improved plant germination, growth, yield, and quality[12,13], for increasing the storage time of vegetables and fruits[14], for increasing biomass of ryegrass, and for efficient removal of ionic contaminants near rhizosphere, in the soil, and in the aquatic environment[15,16]. NC mixed well with the soil could reduce the soil infiltration rate and increase the field capacity effectively[17,18]. However, if NC was applied 5 cm below the soil surface, the infiltration rate and the soil water content at different depths would increase with an increase in NC content[19].

In spite of these studies, sufficient information is not available on the potential effects of NC amendment on soil erosion and nutrient loss. The objective of this study was to examine the

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impact of NC applied to the soil on soil erosion (sediment yield), runoff and nutrient loss via field-scale rainfall simulation tests.

## 2 Materials and methods

### 2.1 Experimental site

The experiment was conducted at Liudaogou catchment, located in the northern part of Loess Plateau (latitude 35°20′-40°100′N, longitude 110°210′-110°230′E), China. The catchment has an area of 6.89 $km^2$ and an elevation between 1081 m and 1274 m. The annual average temperature in the watershed is 8.4℃ (the lowest temperature is –9.7℃ in January, and the highest temperature is 23.7℃ in July). The average annual rainfall is 437 mm (minimum = 109 mm; maximum = 891 mm). The groundwater table is more than 20 m below the soil surface. The desiccation degree is 1.8, with 135 frost-free days, indicating that the experimental site belongs to a semi-arid region.

The experiments were conducted in five field-scale plots, each with a slope of 10° (the average slope in the watershed around the test plots) (Figure 1).

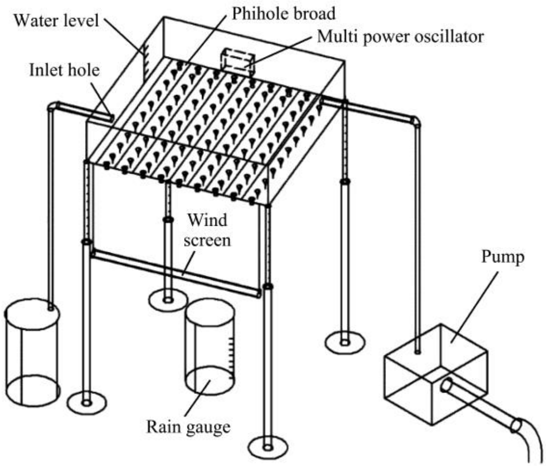



Figure 1 Simulation rainfall with a pinhole rainfall device in the experimental plot

Before the rainfall simulation tests, the physical and chemical characteristics of the experimental soil were determined by the sieving and pipette method[20], and the results are shown in Table 1. According to the USDA soil system, the soil was classified as sandy soil belonging to the Aeolian sandy soil, which is one of the typical soils on the Loess Plateau[21]. The experimental soil belongs to the semi-arid loess region and is characterized by a loose texture and high erodibility and with a very low content of nitrogen-N, phosphorus, potassium and organic material.

**Table 1 Physical and chemical properties of experimental soil**

| Clay /kg·kg$^{-1}$ | Silt /kg·kg$^{-1}$ | Sand /kg·kg$^{-1}$ | Soil texture | Organic content /g·kg$^{-1}$ | pH |
|---|---|---|---|---|---|
| 5.52 | 30.53 | 59.95 | Sandy | 3.54 | 6.21 |

### 2.2 NC amendment

Table 2 shows the basic properties of NC used in this study. The NC made of coconut shell was purchased from the Hainuo Nano Company (Shanghai, China). The diameter of NC was less than 40 nm. To build the three NC bands located in the top, middle and bottom position of the plot (Figure 2), the top 10 cm soil of the test plot was removed to create three bands. The NC was mixed well with half of the removed soil sampled from the test plot at a mass content of 0 (as control), 0.1 kg C/kg soil, 0.5 kg C/kg soil, 0.7 kg C/kg soil, and 1.0 kg C/kg soil, equivalent to an application rate of 0, 5.21 kg C/$hm^2$, 26.15 kg C/$hm^2$, 36.5 kg C/$hm^2$, and 52.1 kg C/$hm^2$ soil. Then the aforementioned mixtures of the NC and soil were applied to those three bands (5 cm in width, 1 m in length, and 5 cm in thickness). Then, the remaining half of the removed top soil was put back to the test plot such that the top 5 cm soil was paced with the same density of the original soil. To make sure the human disturbance was minimized to the lowest degree, the mixtures-buried plots would be aged (left alone) for at least 4 months before the rainfall simulation test was conducted.

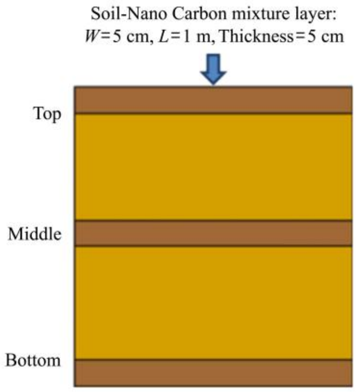



Figure 2 Position of nano carbon bands applied in the plot (1 m × 1 m)

**Table 2 Basic properties of nano carbon**

| Diameters /nm | pH | Water content /% | Ash content /% | Bulk density /g·cm$^{-3}$ | Iodine sorption value /mg·g$^{-1}$ | BET /m$^2$·g$^{-1}$ |
|---|---|---|---|---|---|---|
| <40 | 9.6 | 5.00 | 59.95 | 0.38 | 1300 | 1300 |

### 2.3 Rainfall simulation tests

The rainfall simulation tests were conducted in the aforementioned test plots (Figure 2) using a pinhole rainfall device which was fully described before[22]. The device produced 2.5 mm raindrops from the Polyethylene tubes 2.0 m above the experimental plot. The simulated rainfall intensity was 90 mm/h, which is the average rainfall intensity in summer of the test watershed.

Before the simulated rainfall was conducted, a mixed solution of potassium bromide (1.0 mol/L KBr), potassium nitrate (1.0 mol/L $KNO_3$), monopotassium phosphate (1.0 mol/L $KH_2PQ_4$) as an indicator for soil-dissolved solute was sprayed on the soil surface with a hand-held sprayer at the beginning of the experiments. The quantity of the applied solution was equivalent to 40 g KCl, 40 g $KNO_3$ and 40 g $KH_2PQ_4$ per square meter land.

In each test plot, the surface runoff was collected via the open area at the low end of the test plot. Once the initial runoff started, grab samples were taken with a plastic bottle every 3 min. All samples were transported in an ice box to the laboratory where samples were analyzed immediately. The $NO_3^-$-N, $K^+$, $PO_4^{3-}$ and total solids (TS, representing sediment) concentrations in runoff samples were measured by the ultraviolet spectrophotometric method[23], atomic absorption spectrophotometer HG-9602A, and the Standard Methods[24], respectively. Soil profile samples were collected and measured for water content (gravimetric) and nitrate content for each treatment before and after the experiment. Three different positions were selected: the top, the middle, and the bottom of the plot. At each position, soil samples were taken at the depths of: 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, and 25-30 cm. Each soil sample was divided into two groups. One group was used for measuring the gravimetric water content at 105 ℃ in an oven for 6-8 h, while the other group for measuring the nutrient contents of $NO_3^-$-N, $K^+$, and $PO_4^{3-}$.

After the first rainfall simulation test in each plot, the plot will be left for a certain time (depending the weather but usually 1 month) until the soil water content reach the same water content before the first artificial rainfall. Then another replication took place in the same way.

## 3 Results

Before packing the NC-soil mixtures back to the soil, soil samples with different NC contents were characterized by scanning electron microscopy (SEM). Figure 3 shows that the NC adhered to soil particles. The more NC contents applied into the soil, the more NC could be found on the soil particles. Effects of different NC contents on runoff, sediment yield, soil water content and nutrient loss are described below.

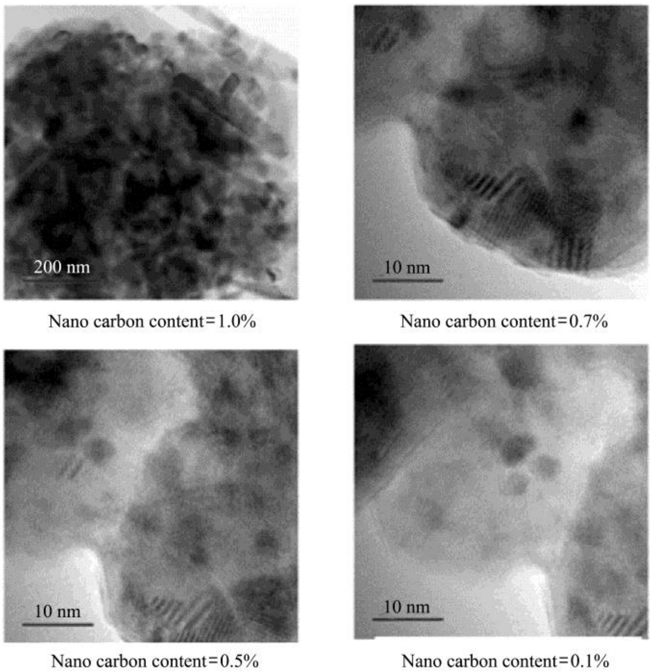



Figure 3 Scanning electron microscopy (SEM) pictures of soil samples with different nano carbon contents

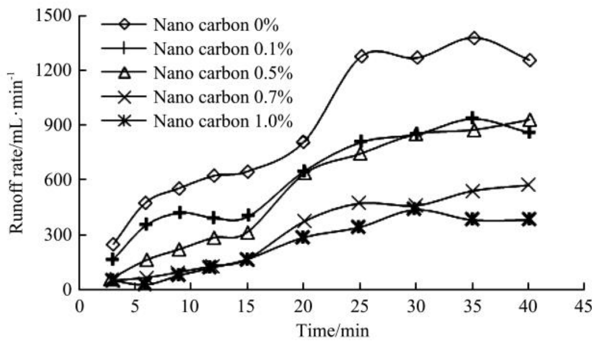
### 3.1 Effects of NC on runoff

Initial runoff time is one of the important parameters to runoff. As shown in Table 3, with an increase in NC content, the initial runoff time became longer, indicating the NC could delay the runoff effectively. For soil in the semi-arid loess region of northwestern China, the runoff will happen once excess infiltration occurs. Therefore, the results of this study indicated that applying NC 5 cm below the soil surface would increase soil water holding capacity, and thus delay the initial runoff time as compared to the control plot (i.e., NC content = 0), which is consistent with the previous studies[25]. Data in Table 3 show that the effects for NC to extend the initial runoff time is more pronounced when the NC content is lower than 0.5%, and such effect levels off as the NC content approaches to 0.7%-1.0%.

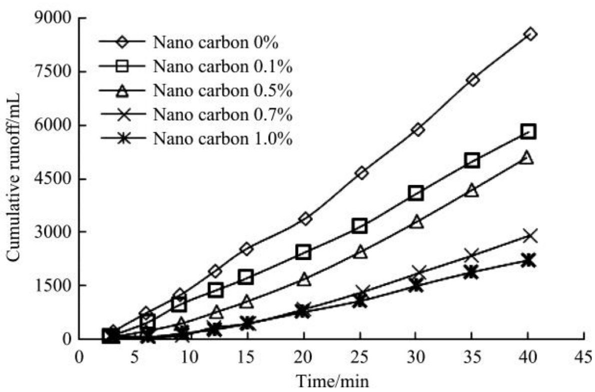
**Table 3 Effects of different nano carbon content on runoff generation**

| Nano carbon content /% | Runoff generation time/min | |
|---|---|---|
| | Test 1 | Test 2 |
| 0 | 3.16 | 3.5 |
| 0.1 | 4.76 | 4.89 |
| 0.5 | 6.87 | 7.12 |
| 0.7 | 8.28 | 8.37 |
| 1 | 8.38 | 8.97 |

Figure 4 shows the effects of NC content on runoff rate and cumulative runoff. In general, runoff rates kept increasing in the first 25 min for each treatment. After 25 min, the increase was not so obvious. As shown in Figure 4a, the runoff rate decreases as the NC content increases. Due to the roughness of the slope, the increase in runoff rates was fluctuated. The cumulative runoff was significantly reduced when NC amendments were used (Figure 4b). When the NC contents were 0.7% and 1.0%, the difference between the two cumulative runoffs was very limited. Figure 4b clearly confirms the beneficial effects of NC on filed water-holding capacity. This may be due to the small size and strong absorption capability of NC for water, which can improve the structure and water holding capacity of the soil[26].




a. Runoff rate



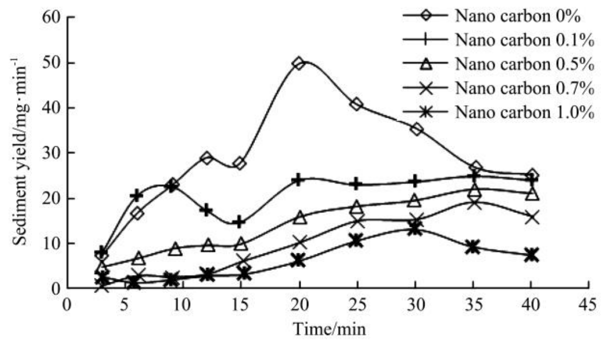

b. Cumulative runoff

Figure 4 Effects of different nano carbon content on runoff rate and cumulative runoff

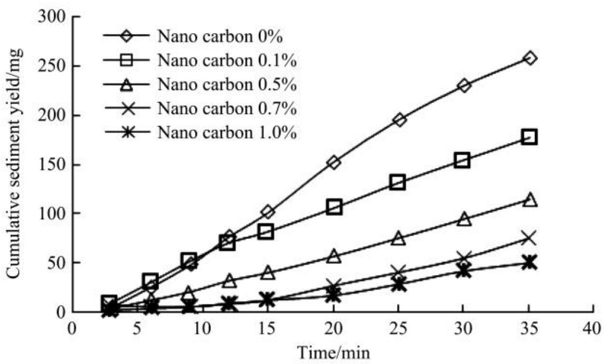
### 3.2 Effect of NC on sediment yield

Sediment yield has been recognized as a major on-site soil degradation process, which could cause serious ecological problems, particularly in the semiarid Loess Plateau and other zones with fragile climate systems[27]. Thus, it is very important to determine the sediment yield rates and sediment yield on the Loss Plateau, which can provide a good basis to facilitate soil erosion control.

Sediment yield (represented by TS in this study) in the control plot increased quickly and fluctuated dramatically during the experiment; it had the highest value at 20 min and then decreased sharply (Figure 5a). This dynamics might result from the change in soil cohesion on the slope surface. At the first stage (about 0-20 min), loose soil particles on the slope were flushed off directly. In the next stage (20-40 min), both soil water infiltration rate and runoff rate became stable. Moreover, the top soil was saturated by infiltrating water, and most of the soil cohesion has been washed out during the first stage, resulting in a decreased sediment yield. As shown in Figure 5a, sediment yield significantly reduced with the increase in the NC content. When the NC contents were 0.7% and 1.0%, the sediment yield of the test plot could decrease to less than 25% of the control plot. Cumulative sediment yield decreased with an increase in NC content (Figure 5b). These results further suggest that NC is likely to reduce soil erosion due to the decrease in storm water runoff.




a. Sediment yield




b. Cumulative sediment yield

Figure 5 Effects of different nano carbon content on sediment yield and cumulative sediment yield

### 3.3 Effects of NC on soil water content

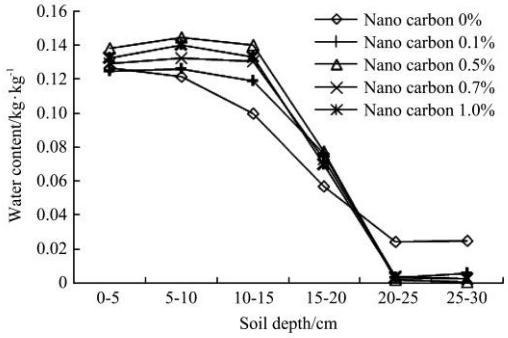
Table 4 and/or Figure 6 indicate several interesting results. Significant differences in soil water content between the soils with and without NC were found. When the NC was applied 5 cm below the surface, the soil water contents tended to be the highest in the NC-soil mixture layer (5-10 cm). The layer (0-5 cm) above the NC-soil mixture layer was more or less the same as that in the control plot. However the layer (10-15 cm) immediately below the NC-soil mixture layer would have a much higher soil water content as compared to the control plot. The average water content of the plot varied greatly with the NC content, with the highest being at 0.5% NC content (Figure 6).

**Table 4 Effects of nano carbon content on soil water content at three different positions**

| Soil profile /cm | Change in water content, $\theta_c^*$ /% | | |
|---|---|---|---|
| | Top | middle | bottom |
| Nano carbon content = 0 (control) | | | |
| 0-5 | 0.117 | 0.119 | 0.121 |
| 5-10 | 0.111 | 0.115 | 0.112 |
| 10-15 | 0.107 | 0.122 | 0.070 |
| 15-20 | 0.078 | 0.064 | 0.028 |
| 20-25 | 0.025 | 0.023 | 0.022 |
| 25-30 | 0.039 | 0.015 | 0.018 |
| Nano carbon content = 0.1% | | | |
| 0-5 | 0.122 | 0.100 | 0.112 |
| 5-10 | 0.131 | 0.135 | 0.134 |
| 10-15 | 0.141 | 0.143 | 0.106 |
| 15-20 | 0.076 | 0.120 | 0.038 |
| 20-25 | –0.003 | –0.001 | 0.000 |
| 25-30 | 0.000 | –0.004 | 0.002 |
| Nano carbon content = 0.5% | | | |
| 0-5 | 0.122 | 0.137 | 0.125 |
| 5-10 | 0.155 | 0.156 | 0.141 |
| 10-15 | 0.151 | 0.143 | 0.125 |
| 15–20 | 0.016 | 0.120 | 0.096 |
| 20-25 | 0.002 | -0.001 | 0.023 |
| 25-30 | 0.001 | -0.004 | 0.032 |
| Nano carbon content = 0.7% | | | |
| 0-5 | 0.155 | 0.134 | 0.128 |
| 5-10 | 0.120 | 0.139 | 0.122 |
| 10-15 | 0.127 | 0.119 | 0.112 |
| 15-20 | 0.097 | 0.056 | 0.074 |
| 20-25 | –0.001 | 0.008 | –0.007 |
| 25-30 | 0.002 | –0.006 | 0.004 |
| Nano carbon content = 1.0% | | | |
| 0-5 | 0.134 | 0.127 | 0.135 |
| 5-10 | 0.120 | 0.120 | 0.123 |
| 10-15 | 0.129 | 0.120 | 0.123 |
| 15-20 | 0.166 | 0.103 | 0.124 |
| 20-25 | 0.008 | 0.010 | 0.076 |
| 25-30 | 0.011 | 0.007 | 0.009 |

Note: * $\theta_c$ = change in soil water content, calculated by $\theta_a$-$\theta_i$ with $\theta_a$ and $\theta_i$ = the soil water content after and before rainfall simulation test, $cm^3/cm^3$, respectively. All the $\theta_c$ values in the table are the mean value of the two replicates.

This result is consistent with the previous study. The water holding capacity and hydraulic conductivity of soils could be increased with the presence of NC. Table 4 and Figure 6 show that when the NC content was 1%, the further improvement on the soil water content was not observed. Therefore, adding too much NC (e.g., >0.5%-0.7%) may not be necessary if the purpose is to enhance the soil water content. When the depth was 15 cm below the surface, the soil water content of the plot with NC amendment decreased sharply as compared with that in the control plot (Figure 6 and Table 4). A possible reason for this is that the soil with NC could adsorb more water in that layer or the layer next to it, which could result in less water flowing into deeper soil. This result is consistent with previous studies[17,19]. Therefore, due to the existence of NC layers that have strong absorption capacity for water, the soil could hold much more water than those without NC amendment, resulting in an effective reduction of soil water deep percolation. Soil water contents also changed with the position of the NC band in the plot. In general, the soil water content in the 10-20 cm of the NC amended soil is ranked as top-band > middle-band > bottom-band (Table 4). Below 20 cm, the NC effect on soil water content was not pronounced (Table 4 and Figure 6).




Note: Each data point is the average of top-, middle-, and bottom-bands from Table 4.

Figure 6 Effects of nano carbon content on average changes in soil water content after and before rainfall simulation tests.

### 3.4 Effects of NC on nutrient loss

The concentration of $NO_3^-$-N and P in the runoff of the plot with NC amendment had the same trend as those in the control plot, that is, the concentration of each ion reduced fast in the initial 15 min and then slowly after 15 min. This trend mainly was controlled by the raindrops and solute concentration in the soil at the beginning. During the initial a few minutes after runoff began, the more solute in the soil profile, especially on the surface, the more solute in the runoff. However, with the rainfall simulation experiment went on, the $NO_3^-$-N and P in deep soil could not be released easily due to the strong absorptivity of soil particles, resulting in the concentration of $NO_3^-$-N and P in the runoff leveled off. On the other hand, potassium could dissolve in the soil water and runoff easily, and thus, the concentration of potassium in runoff kept decreasing during the experimental period.

Figure 7 indicates that, with the application of NC to the soil, the runoff and thus the corresponding nutrient loss were reduced effectively, especially when the NC contents were 0.7% and 1.0%. Therefore, NC could reduce the nutrient loss because of the reduced quantity of runoff (see Figure 4) as well as the reduction of concentration in the runoff. Figure 7 also indicates that adding 0.7% or 1% NC would result in very similar effect on the loss of $NO_3^-$-N and P. Together with the reduced runoff shown in Figure 4, it could be confirmed that NC could reduce the nutrient loss effectively.

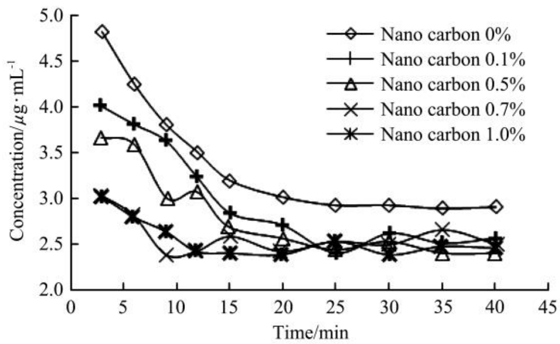
Figure 8 shows that the concentrations of the three ions in the sediment decreased sharply with the time at the initial 20 min, and leveled off gradually after 20 min. NC only had a minor effect on the nutrient concentration in sediment at the very first a few minutes, and little effect could be found after 15 min. However, combining the sediment yield data shown in Figure 5 with Figure 7, the total nutrients (solute) in sediment was reduced by NC as well.

## 4 Discussion

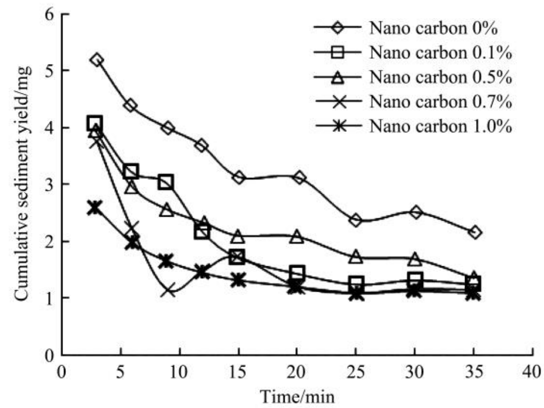
On the Loess Plateau of China, heavy rainfall during summer cause severe soil erosion on the hillslope, which will lead to the loss of the soil nutrient. Effective strategies for controlling soil erosion and nutrient loss (e.g., terracing, afforestation, natural rehabilitation) have been carried out on the Loess Plateau since the 1950s. The main mechanisms of all these strategies are almost the same, that is, to reduce the soil and nutrient loss from the top slope to the bottom slope. Increasing the infiltration rate on the top slope would effectively reduce the runoff, sediment yield and nutrient loss. Furthermore, as we mentioned above the runoff will happen once excess infiltration occurs. Therefore, the infiltration rate is one of the key factors in assessing the effect of NC on water and soil loss. Based on the experimental data, the average infiltration rate was calculated as follows[28]:

$$i_a = (Pt\cos\alpha - \frac{10R}{S})/t \tag{1}$$

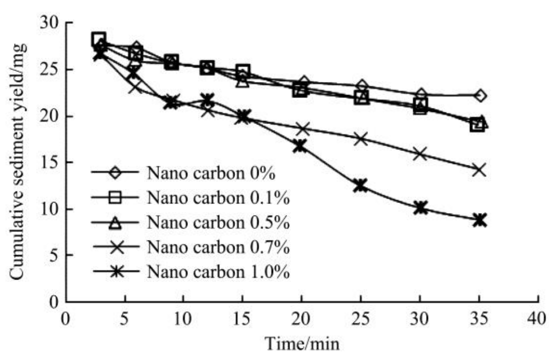
where, $i_a$ is the average infiltration rate on the slope, mm/min; $P$ is rainfall density, mm/min; $\alpha$ is the slope degree; $R$ is the runoff, mL; $S$ is the area of the plot, cm$^2$; $t$ is time, min.




a. Nitrate-nitrogen

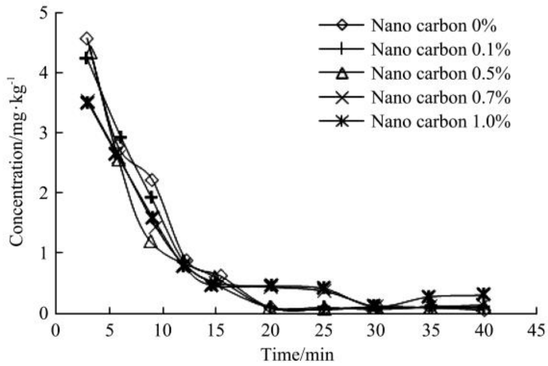



b. Phosphorus

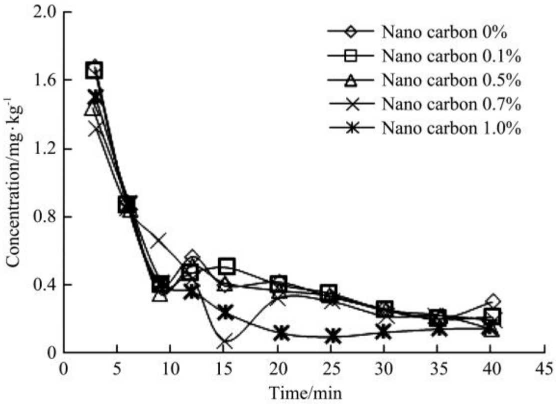



c. Potassium

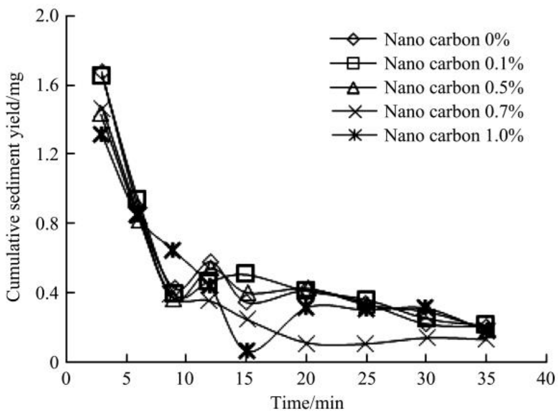
Figure 7 Effects of nano carbon content on nutrient loss in runoff




a. Nitrate-nitrogen




b. Phosphorus




c. Potassium

Figure 8 Effects of nano carbon content on nutrient loss in the sediment of runoff

Figure 9 shows the infiltration rate changing with time in the plots with different NC contents. The average infiltration rate decreased obviously at the first 15 min and then kept constant, and with an increase in NC content, this phenomenon was more obvious. When the NC contents were 0.7% and 1.0%, little variation was found, which was similar to the results obtained in the lab[17]. It is apparent that simulated rainfall produced heavy impact on each plot. On the control plot, the impact caused heave erosion, resulting in heavy deposition of the soil in the collection area down the slope due to detaching and transporting vulnerable soil directly by means of rain splash. Raindrops also broke the clump of soil into finer particles, which easily moved away by unhindered flowing water. On the plots with applied NC, infiltration was maximized in the soil, resulting in strongly cohesive soil particles and preventing them from being eroded along the slope.

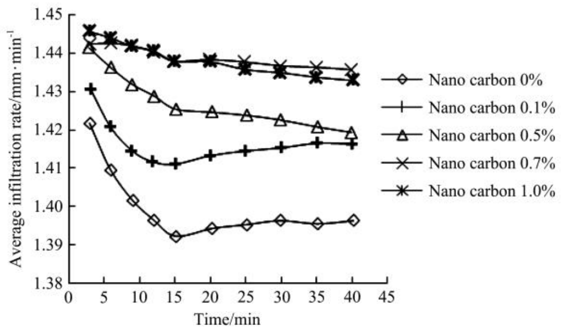
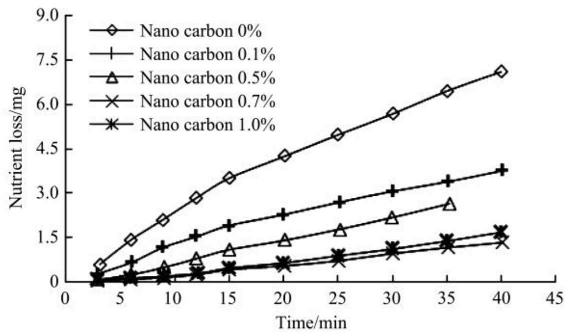



Figure 9 Effects of different nano carbon content on average infiltration rate

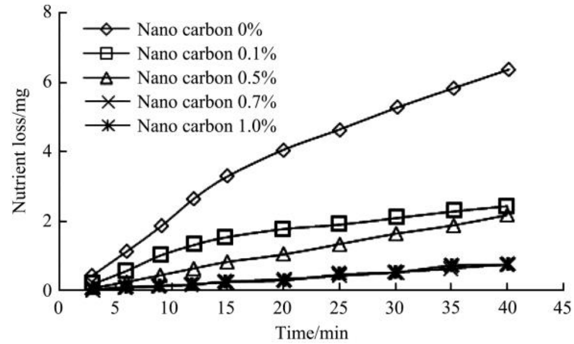
In order to show the effect of NC on nutrient loss, the nutrient loss both in runoff and sediment was calculated with the following equation[28]:

$$m(t)=c(t)\times r(t)+C'(t)\times s(t) \quad (2)$$

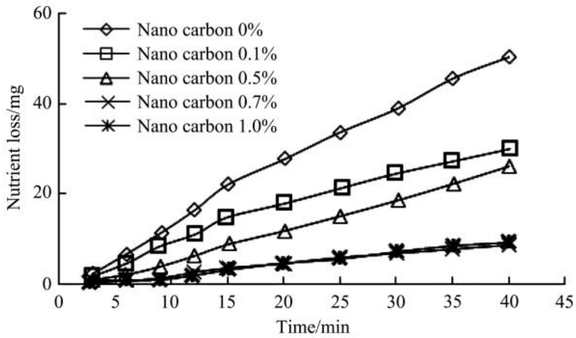
where, $m(t)$ is the nutrient loss at time t, mg/min; $c(t)$ is the nutrient concentration in runoff at time $t$, mg/L; $r(t)$ is the runoff rate at time $t$, cm$^3$/min; $C'(t)$ is the nutrient concentration in sediment at time $t$, mg/kg; $s(t)$ is the sediment yield at time $t$, kg/min; $t$ is the time, min.




a. Nitrate-nitrogen




b. Phosphorus




c. Potassium

Figure 10 Effects of different nano carbon content on nutrient loss

From Figure 10, it could be easily found that nutrient loss in the control plot became much larger as the experiment went on.

Nutrients would loss easily under the combined force of raindrop splash and runoff scour. When the subsoil was eroded, deeper soil could keep on supplying the nutrients, which would accelerate nutrient loss. In contrast, the nutrient loss in the NC amended plots increased more slowly with an increase in NC content. When the NC contents were 0.7% and 1.0%, little difference could be found and the nutrient loss was the lowest, indicating that 0.7% NC dose was the most efficient in conservation of nutrient loss. Comparing with the nutrient loss in the control plot, the nutrient loss in NC amended plots containing 0.1%, 0.5%, 0.7% and 1.0% NC could be decreased by 47%, 55%, 76% and 81% for $NO_3^-$, 61%, 66%, 88% and 87% for phosphorus, as well as 41%, 48%, 82% and 83% for potassium, respectively. Therefore, this study supports the hypotheses concerning the positive effects of NC on water infiltration and nutrient loss in soil.

## 5 Conclusions

In this study, the effect of nano carbon on soil erosion and nutrient loss was studied with rainfall simulation tests in artificial plots. The results showed that the sandy soil on the Loess Plateau with 0.7% NC addition (36.47 kg/hm$^2$ on a mass basis) could improve soil water runoff, sediment yield and nutrient loss in the semi-arid loess region of northwestern China, in addition to preventing soil water from deep percolation. Therefore, NC may have a great potential in soil erosion control on the Loess Plateau of China.

However, it should also be pointed out that this study still has some limitations. For example, one still does not know what the effects of the depth of the NC bend buried in the soil are, and what the efficiency of the NC band will be as a function of (1) burying time, (2) plot conditions (e.g., slope, soil type, etc.), (3) the existence of plants or vegetation in the band areas, and (4) different weather conditions, which warrant the future studies. Nevertheless, based on our results, we deduced that the major reason for reduction of soil loss after the addition of NC was the strong absorbility due to NC's great specific surface area, which could accelerate the soil water infiltration. Furthermore, NC has also been reported to influence soil physical properties, such as water retention, porosity and hydraulic conductivity[27,29]. Indeed, we found that NC had a positive effect on soil erosion with reduced volumes of runoff water and soil detachment rates.

Moreover, NC could be buried easily as we did in this study as compared with those unpractical methods that are time and labor consuming. All we need to do is to apply the NC with about 36.47 kg/hm$^2$ on a mass base in a band 5 cm below the surface. The work could be much easier if the machine like a seeder planter could be adopted to apply the NC directly to the soil at a certain speed and a certain level.

Finally, the price of NC made of coconut shell is $10-$16 per kg ($365-$584 per hm$^2$). Comparing to other soil and water conversation project, like terraces and reforest[30], the costs will be much lower. Besides, NC can be made from other residual biomass, which turns trash into treasure and is good for sustainable development. Furthermore, the water and nutrient could also be kept in the soil for the plant growth, which will help with the ecological construction. Therefore, banding application of NC is an effective option for control of soil erosion and nutrient loss with additional benefits to agriculture and the ecosystems.

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