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The application of nanocellulose product to enhance the water retention of sand particles

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ABSTRACT: This research aims to investigate the application of nanocellulose (NC) for enhancing water retention in different sand particles. The water-holding capacity as well as surface evaporation of sand mixed with NC were investigated. Three sand particles such coarse sand (2.0-0.425 mm), medium sand (0.425-0.075 mm), and fine sand (0.075-0.053 mm) were mixed with NC in various contents as 1: 400, 1: 300, 1: 200, 1: 100, 1:75, 1:50, 1:25, 1:20, and 1:10 (NC : sand, W/W). The experiment includes the control that without NC. The water-holding capacity (WHC) of all treatments were measured. The surface evaporation was carried out only two contents of NC (1:50 and 1:100) under different environments (in the oven, room temperature, balcony, and outside). These contents of NC were representative of high and low NC concentrations. The surface evaporations of all sand particles were measured follow by the time. The results indicated that NC significantly improve WHC and maintain water for all sand sizes. The maximum WHC was showed at content 1:50 of NC for all treatments. The relationship between NC content and WHC were not linear. Change of WHC of sand depended on NC content and sand particle size. The coarse and medium-sand showed the increased WHC higher than fine-sand. The NC could improve micropores in coarse and medium sand for water storage. Whereas in fine sand, the fraction of macropore was increased instead. The result of surface evaporation showed that high NC content (1:50) gave high rate of surface evaporation. However, the NC could maintain moisture in sand longer than without NC. Under the different environment, outside showed the highest evaporation rate for all treatments due to ambient factors. The NC product showed different benefit for particle size. For coarse to medium particle, NC acts as surface area to absorb water on particle surface and into sand structure. In case of fine particle, NC showed vital role as cementing agent to combine particle and promote aggregation. Its efficiency was promoting macropore fraction for water movement. The NC could be used as soil conditioner to enhance water-holding capacity for coarse particle and promote aggregation for fine particle.
Keyword: sand particles; nanocellulose; water-holding capacity

Introduction

Soil resource is the major factor of agricultural production which needed to be first considered for management in order to achieve maximum production efficiency. Soil properties include soil fertility, biodiversity and physical properties (Soil science staffs, 1998). The hydraulic property such as water-holding capacity of soil is the one of physical properties that indicate the potential of water in soil for plant use. Soil water storage is the most important function of the soil physical property, in addition to support nutrients and soil activities for plant growth. Soil water storage is also related to soil texture and soil structure (aggregation, pore-size distribution), especially. The soil structure indicates the ability of moisture maintaining in the soil. In arid areas, almost soils are coarse texture, more sand fraction. They are low water storage due to poor structure and coarse texture. These two soil

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properties are cause of lower water absorption in arid zone (Warrick, 2002). The coarse-texture soil has very low water retention because of low specific surface area. Especially, sand fraction in soil is the most important particle-size in coarse-texture. Sand particle limits soil water and nutrient absorption. In arid region sand particles are the critical problem for erosion due to lack of moisture storage. To increase the ability of moisture retention of sand, the management should focus on improving the structure, useful pores, and absorption area. Soil structure can be improved in many methods, i.e. adding organic matters such as manure, compost or green manure to the soil. Organic substances may help to promote aggregation, a good soil structure. Aggregation increases a water storage pore. Although, adding organic matters is a widely popular method but the improvement of soil physical properties take time in many years. According to previous reasons, the development of materials such nanoclay (montmorillonite, vermiculite) as well as nanocellulose have been interested for researchers. Nanocellulose (NC), cellulosic extracts or processed materials, is defied nano-scale structural dimensions (Abitbol et al. 2016). NC can be produced from plants, animals or bacteria. The extracting cellulose was procedure by means of chemical procedures such as acid hydrolysis, chlorination, alkaline extraction, and bleaching (Morán et al., 2007). NC can be employed in several fields, such as nanocomposite materials, wood adhesives, supercapacitors, batteries, and catalytic supports. They are as strong as Kevlar but the same water-absorption capacity as pampers. Nanocellulose was be used to replace glass fiber material for automobile production. NC promoted this production to high strength but lighter weight (Plastics Institute of Thailand, 2016). NC has a high molecular adsorption area and absorbed water into the molecule about 100 times by weight (Jiang, 2014). Its properties are a very high adsorption area of 153-284 m^2g^{-1} (Sehaqui, 2011). Therefore, it is an interesting alternative application of NC to enhance soil water storage and maintenance soil moisture. This research aims to study the possibility of using NC products as soil conditioner to enhance water-holding capacity (WHC) and decrease water loss of sand via surface evaporation.

Material and method

The experiment was carried out in laboratory. Three sizes of sand particles (ISO14688-1: 2017) were coarse sand (2.000-0.425 mm), medium sand (0.425-0.075 mm), and fine sand (0.075-0.053 mm). Each particle was mixed with NC paste (supported by PheeDoo Cooperation Inc.) by different contents (1:400, 1:300, 1:200, 1: 100, 1:75, 1:50, 1:25, 1:20, and 1:10) (NC : sand, W/W). The treatment included control (without NC) as well. This NC was provided from plant part. It is white-paste and viscous material. The sand mixed with NC was incubated 1-2 hours in order to reach saturate. The initial moisture content (θ_v) of mixed materials were 0.20, 0.25 and 0.45 for coarse, medium and fine sand, respectively. The saturated moisture of mixed material depends on sand size particle. The water-holding capacity (WHC) (Hazelton and Murphy, 2007) was estimated by the calculation of the fraction between adsorbed water in material and dry-weight (100 g) of material. As well as pore size distribution of sand mixed with NC were measured. To investigate the effect of NC on surface evaporation only two NC contents were used (1:50 and 1:100). These were representative of high and low contents of NC. The experiment was carried out under various atmosphere in which different temperatures. The condition consisted of in the oven (45-55 ºC), room temperature (25-28 ºC), balcony (25-32 ºC) and outside environment (25-45 ºC). The surface evaporation was estimated based-on water loss (cm^3 H_2O/area.time) by area and time of each treatment under different environments (Hazelton and Murphy, 2007).

Result and Discussion

The effect of NC on water-holding capacity of sand particles

The results showed that the WHC of sand mixed with NC significantly increase (**Table 1**). The WHC of mixture materials were higher than without NC (control). The coarse sand (2.000-0.425 mm) mixed with NC showed the highest water storage than others. The NC content 1:50 was the highest WHC for all particle sizes. The lowest WHC was found different NC content. It depended on size particle. The lowest WHCs were found at 1:300 (coarse and medium sand) and 1:10 (fine sand) NC contents. Coarse and medium sand mixed with NC showed the higher WHC than without NC around 50 percent. Whereas fine sand (0.075-0.053 mm) mixed with NC, the WHC was increased about 20 percent compare to without NC. The application of NC for coarse and medium sand could enhance WHC but fine sand showed different result. As similar result to Akhter et al. (2004), reported hydrogel amendments could improve water retention capacity of sandy loam (coarse-textured soil) and loam (medium-textured soil) soil. The hydrogel amendment was effective in improving soil moisture availability and thus increased plant establishment. As well as Herawati et al. (2021), studied the strategy for water-holding capacity in sandy soils by organic amendment such as cow dung, rice husk biochar and clay-soil. They result showed that the application of organic soil amendments able to improve the soil's physical properties through increasing the water-holding capacity of sandy soil to increase crop productivity. Mi et al. (2020) investigated the effect of bentonite as soil amendment on field water-holding capacity in semi-arid region, northern China. Their result showed that the application of bentonite significantly increased field water-holding capacity and plant available water in the 0–40 cm layer. According to previous researches and this study indicated that both soil amendment from organic or synthetic-organic can enhance soil water retention capacity, particularly, coarse-textured soil as sandy soils.

Table 1 The average of WHC (%) and statistical analysis for sand particles mixed with NC in different contents

Particle Size	Coarse-sand	Medium-sand	Fine-sand
NC ratio (w/w)	Water-holding capacity (%)		
control	33.26d	34.98ef	40.69f
1:10	49.21c	54.48c	47.76e
1:20	61.42b	63.84b	59.14bc
1:25	70.59ab	69.35a	63.95ab
1:50	74.02a	70.67a	65.24a
1:75	61.52b	66.24ab	58.90bc
1:100	71.95a	61.96b	53.50d
1:200	60.62b	40.05de	55.85cd
1:300	38.47d	36.46f	52.97de
1:400	-	43.64d	51.83de
% C.V.	4.51	2.78	2.41
F-test	**	**	**
P-value	0.000	0.000	0.000
SEM	1.981	1.090	0.988

**,* = Significant at 0.01 and 0.05 probability levels, respectively, SEM (Standard error of mean)

The relations between NC content and WHC were not linear for all sand particles. The WHC of sand mixed with NC was increased follow by increasing of NC content. This relation showed only at low concentrations of NC (1:400, 1:300, 1:200, and 1:100 w/w). The WHC of all treatments were at 1:50 content and trended to decrease even NC contents high (1:25, 1:20, and 1:10). By probability, high content of NC (1:10) should increase water adsorption in sand. It would be that NC adding a huge of cementing agent into the sand particles. This cementing agent acted as a bonding and causing the aggregation instead water adsorption. This result in the higher fraction of macropore (>30 μm) in the sand at high content of NC (**Figure 1**). These macropores were transmission pores for drainage and aeration. Therefore, the result indicated that the higher NC content mixed with sand, the lower WHC. While high NC content related to fraction of macropores, especially, fine sand. The reason would be the complicate of NC contents and their role as cementing agent or absorbent surface in sand structure. Their roles might be derived in both functions. Some act as cementing agent to bond sand particles. Whereas some act as absorbent of sand to attach water molecules. The change of pore size distribution (**Figure 1**) could describe previous results. These graphs indicated that sand mixed with NC affecting on mesopores (30-0.2 μm, useful pore and water storage) in both of coarse and medium sand. The mesopores were more than 50 percent compared to without NC. Which increased significantly fraction of useful pore to storage water in sand. The coarse and medium sand mixed with NC content 1:50 showed the higher fraction of storage water more than 1:100. The useful pore of medium sand was higher than coarse sand for both NC contents (1:50 and 1:100). In the fine-sand, the result was diffed from the lathers. At the initial, fine-sand has fraction of mesopore more than lathers. After mixed with NC, mesopore of fine-sand was decreased, while macropores increase. The result showed that fine-sand mixed with NC would increase the ratio of the macropores (> 30 μm) more than others in both NC contents (1:50 and 1:100). The changes of pore size distribution of sand particles mixed with NC could be described that NC having an important role to enhance sand structure. NC did not only increase WHC of sand, but it could improve aggregation of sand also. This might reduce sand erosion in arid region by wind. The aggregate stability and moisture maintaining of sand are the important factors for reducing a risk of wind erosion (Tatarko, 2001).

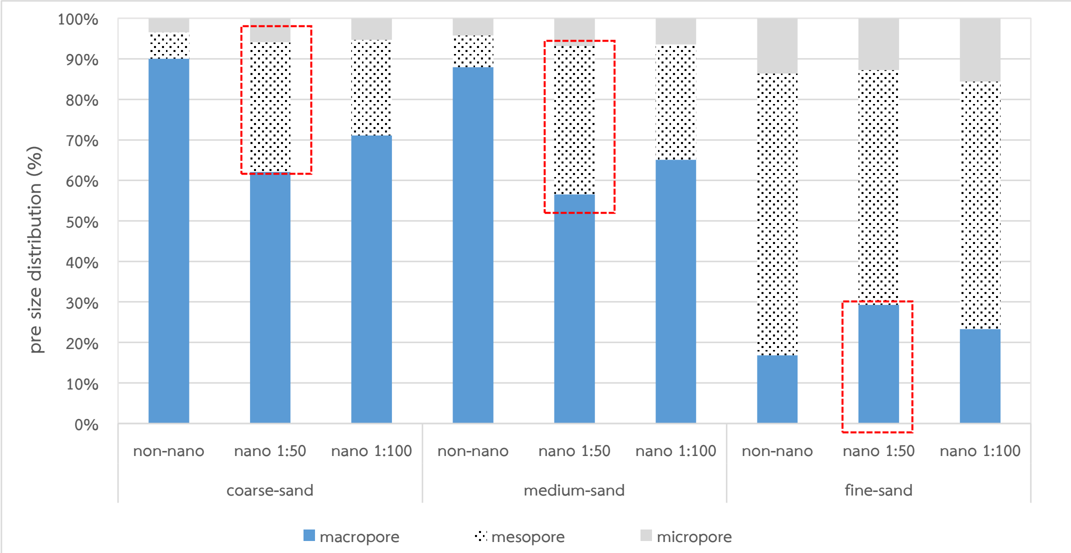

Figure 1 The change of pore size distribution of sand particles mixed with NC contents 1:50 and 1:100 (macropore >30 µm, mesopore 30-0.2 µm and micropore < 0.2 µm)

The effect of NC on surface evaporation of sand

This study of the evaporation rate from sand surface was carried out in two contents of NC (1:50 and 1:100) and under different environments such as in the oven, room temperature, balcony and outside. The results showed that the evaporation rate of sand mixed with NC was higher than without NC for both concentrations. Whereas the evaporation of sand mixed with NC showed the relatively stable and the moisture maintain in sand longer than without NC. The sand without NC showed decreasing rapidly evaporation due to low water adsorption and low water storage in sand. And this case soil moisture approaching the permanent wilting point (PWP) faster than mixed with NC. The result indicated that water storage in sand without NC was disappeared quickly compared to the mixed with NC.

In the oven (**Figure 2**; 45-55 °C), showed that the evaporations were high for all treatments at the beginning. After that the evaporation gradually decreased following time. The sand mixed with high NC content (1:50) showed the higher evaporation rate than others for all particles due to macropore fraction. The sand without NC, evaporation rate was continue decreasing by related to decreasing of water in soil. This soil moisture was approached dry point about thirty hours for coarse and medium-sand. Exceptional, fine sand kept soil moisture longer thirty hours due to capillary tension of micropore. For high content of NC (1:50), the evaporation rate was slightly constant after eighteen hours for all sand particles. But at low content (1:100) was reduced and constant until the soil moisture reaches the PWP after forty-two hours. Fine-sand showed the evaporation change differs from coarse and medium particles. The low NC content (1:50), the evaporation rate of fine sand was relatively constant from twelve to thirty hours and gradually increased after the thirty hours. Moreover, this showed the water maintain in fine-sand longer than coarse and medium. Fine sand could maintain water at least forty hours. Because fine particle included more fraction of micropore and higher specific surface area than others. The higher micropore and surface area, the higher matric potential to storage water in soil as well.

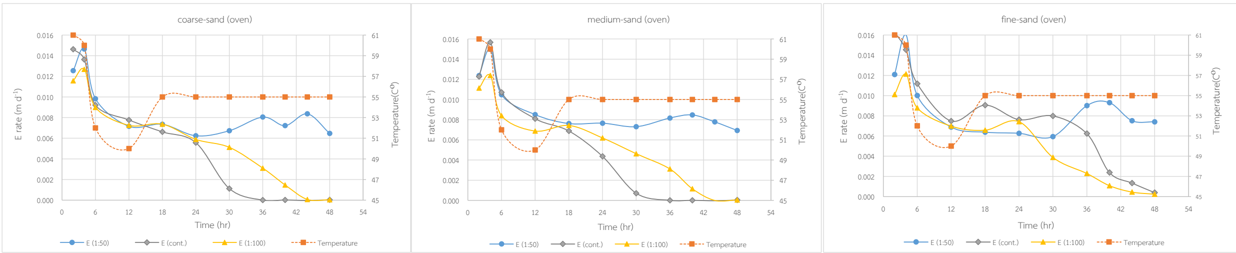

Figure 2 The surface evaporation rate of sand mixed with NC (1:50 and 1:100) in the oven (45-55 degrees Celsius), (E(1:50)=Evaporation of NC content 1:50, E(1:100)=Evaporation of NC content 1:100 and E(cont.)=Evaporation of sand without NC)

In the room (**Figure 3**; 25-28 °C), found the maximum evaporation was about 0.004 m d^{-1}. Which was slightly low evaporation compared to other environments. For all NC contents as well as sand particles showed the same pattern of evaporation change due to stable of the ambient air in the room. Moreover, the surface evaporation for all treatments were changes a bit during thirty-five hours. Even though, the result showed that sands mixed with NC could maintain moisture for more than 36 hours. While without NC, surface evaporation of sand was high and water loss rapidly and soil moisture reached air dried before 24 hours.

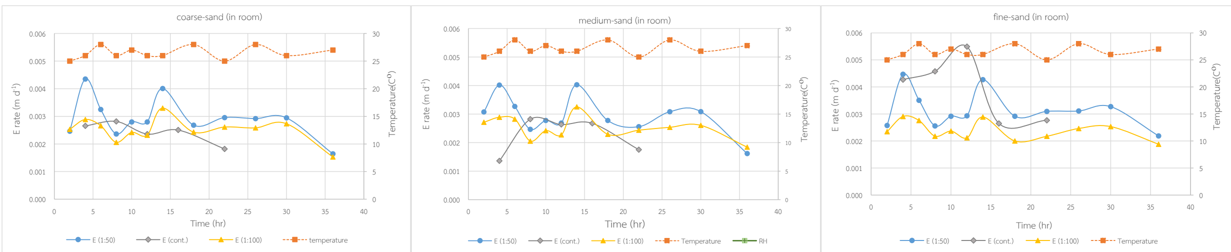

Figure 3 The surface evaporation of sand mixed with NC (1:50 and 1:100) under room temperature (E(1:50)=Evaporation of NC content 1:50, E(1:100)=Evaporation of NC content 1:100 and E(cont.)=Evaporation of sand without NC)

Balcony environment (**Figure 4**; 25-35 °C), showed the maximum surface evaporation about 0.005 m d^{-1}. The high evaporation rate might cause by wind and relative humidity outside the room. For all NC contents as well as sand particles showed the same pattern of evaporation change. The evaporation change on balcony was relatively low and nearby the room temperature. This environment showed a bit change of evaporation rate for all treatments. The sand mixed with NC could maintain moisture longer than thirty-sixth hours. In case of sand without NC found that surface evaporation higher and decreasing after twenty-one hours. And water in this sand was reached permanent wilting point before twenty-four hours the same result as in room condition.

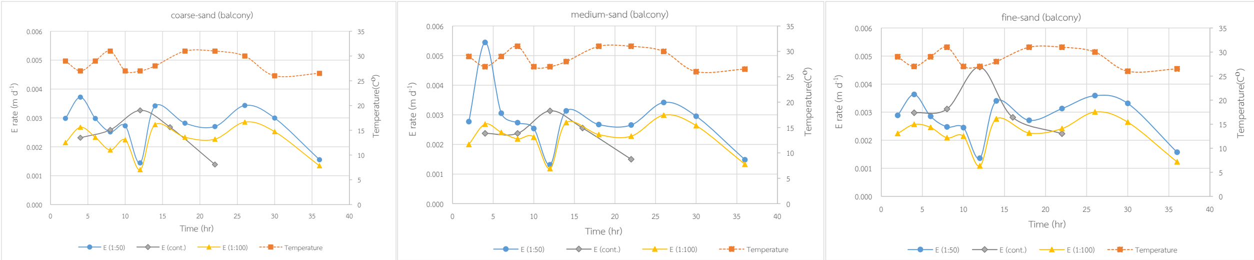

Figure 4 The surface evaporation of sand mixed with NC (1:50 and 1:100) under balcony environment (E(1:50)=Evaporation of NC content 1:50, E(1:100)=Evaporation of NC content 1:100 and E(cont.)=Evaporation of sand without NC)

Outside environments (**Figure 5**; 25-45 °C), showed the highest evaporation (0.040 m d^{-1}). At the beginning, the evaporation for all treatments were high and gradually decrease follow by the time. The high NC-content (1:50) showed higher evaporation rate than low content (1:100) and without NC. The evaporation of high NC-content (1:50) was uncertainty changes depending on the temperature and relative humidity outside during the day. The low content of NC (1:100) showed decreasing evaporation and slightly to constant around ten hours. The sand without NC showed that the evaporation decreasing continually by related to the decreasing of water in sand. Without NC soil moisture was approached dry point about twelve to fourteen hours for coarse and medium sand. The evaporation changes of coarse and medium sand were similar each other. In the case of fine sand, found that the pattern of evaporation was a bit differ from lathers. The high content of NC (1:50) showed the result as similar as coarse and medium sand. But low NC content (1:100) showed that the evaporation decreases continuously in ten hours and the trend approached dry point after sixteen hours. This was longer than coarse and medium sand.

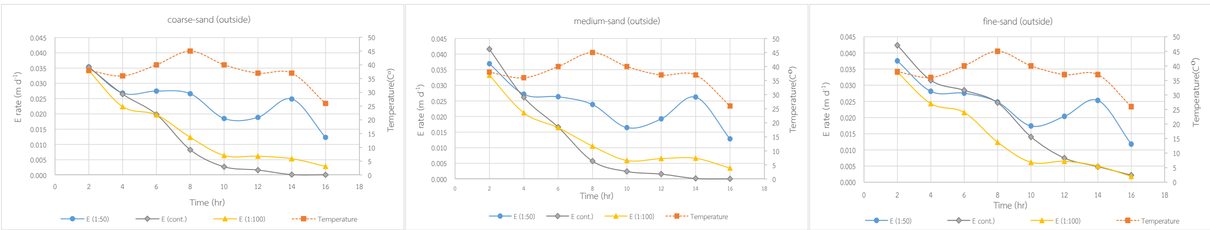

Figure 5 The surface evaporation of sand mixed with NC (1:50 and 1:100) under outside environment (E(1:50)=Evaporation of NC content 1:50, E(1:100)=Evaporation of NC content 1:100 and E(cont.)=Evaporation of sand without NC)

The result indicated that the different environments affect on evaporation rate of sand mixed with NC. By the outside showed the highest evaporation rate for all treatments compare to others due to turbulent ambient air. This caused by lot of factors that determine the evaporation such as sun radiation, relative humidity, and wind. The content of NC influenced on surface evaporation as well. The high content of NC (1:50) showed higher evaporation rate than low content of NC (1:100). According to previous result, high content of NC could enhance aggregation of sand particles. This increased the fraction of macropore in sand. Even high NC content could increase evaporation rate of sand due to higher macropores, but surface area of NC might absorb water in sand longer. The pore size distribution supported the water storage and movement in soil. The result of this study indicated that NC-product could enhance water-holding capacity of sand. The increasing of water absorption this case may imply the same situation in coarse-textured soil in arid-region. Thus coarse-textured soil can be promoted the water-holding capacity by means of nanocelluluse product as well. The result accorded to researches as follow:

Sehaqui et al. (2011) studied the dispersion of nanofibrillated cellulose (NFC), planted nanocellulose, nanofibers in the hydrocolloid. They found that nanofiber was very well preserved in the aerogels. The average diameter of the NFC nanofibers in the aerogels is around 10–18 nm corresponding to specific surface areas as high as 153–284 m^2 g^{-1} that very high surface for absorption. This research indicated that NC from plants having high specific surface area that may apply with appropriate coarse-texture of soil, low specific surface area, to increase their ability for water or fertilizer absorption.

Demitri et al. (2013) studied Potential of Cellulose-Based Superabsorbent Hydrogels as Water Reservoir in Agriculture. They focused on the cultivation of tomatoes with hydrogel-amended soil demonstrated that the hydrogel could significantly increase the water retention capability of the soil, as well as allowing the sustained release of water to the plants for a prolonged time, without additional watering needed. This indicated that cellulose could be applied in agriculture field as organic substance to increasing hydraulic property of soil and absorbent for nutrients as well.

Abitbol et al. (2016) mentioned that NC has been increasing interest for a range of applications relevant to the fields of material science and biomedical engineering due to its renewable nature, anisotropic shape, excellent mechanical properties, good biocompatibility, tailorable surface chemistry, and interesting optical properties. The developments, particularly in the fields of coatings and medical devices, clearly exists. Pushing the boundaries of NC further into other fields and high-performance functional plastics, to create organic materials with tunable, ‘smart’, and biomimetic characteristics will be of particular interest for the future, especially as cost-effective commercial sources of NC continue to emerge. Currently, the applications of nanocellulose may be somewhat limited by availability and cost, however the outlook is promising as more companies and researchers look toward these particles for solutions to existing challenges. This is clearly for many performances of NC, even, their cost still expensive for production but very interest to apply in high economic plant material for land-scape in city life in which lot of high building and need green zone.

Yi and Zhao (2016) studied the solution to control desertification in the Nan’an District of Chongqing, China. The proposition of desert “soilization” based on the realization of sand “soilization,” which presents a promising alternative to the prevailing methods of desert control. Sand “soilization,” i.e., the turning of sand into “soil,” is a remarkable transformation based on the revelation of the eco-mechanical attributes of soil. The result indicated that sand layers with thicknesses of 10–20 cm, which were obtained by mixing sand with a modified sodium carboxymethyl cellulose (CMC) solution (containing 2% modified CMC and 5% compound fertilizer) at a weight ratio of 1: 0.15, were placed on top of the plain sand layer in separate sections. Three types of commercially available sand for building and construction (clean river sand), with different fineness moduli of 1.22, 2.97, and 3.71 and without any soil content, were subjected to “soilization”. In addition to these river sands, three other granular materials (machine-made sand from stone, sand mixed with machine-made sand from stone, and sand mixed with saw-dust) were also used in the planting after "soilization.". This showed that cellulose from plant-part can used to improve sand particle into similar properties as soil in order to planting. Then improved sand properties can control desertification in arid land as well.

Bauli et al. (2021) reported carboxymethyl cellulose (CMC) hydrogels were produced via chemical crosslink with citric acid and filled with NC, clay minerals (montmorillonite or vermiculite), in different contents. The result showed that CMC hydrogels filled with NC, increasing the hydrogen bond energies and reflecting in the water absorption. And NC could be applied as coat-fertilizer to make it a slow-release that reduce fertilizer loss. Then NC could be used as absorbent material to increase water storage efficiency. According to this study, NC can increase hydrogen bond to absorb water molecules. Then would be possible to apply NC as soil conditioner in arid region, especially, in which lot of coarse texture that high sand component to increasing water holding capacity. NC is not only high performance of absorption site but it is eco-friendly material that can be decomposed become soil organic matter also.

Barajas-Ledesma et al. (2021) found that the water retention of soil increases with application rate of Carboxylated nanocellulose superabsorbent (SAP). The extent of this increase in water holding capacity and the profile of water retention over time are dependent on the type of SAP. These water retention properties decrease as the superabsorbent degrades. Soil amended with this superabsorbent remains moist the longest. This increase in water content prolongs the period of water available for the plant, delaying the permanent wilting point by up to 20 days. The research confirmed the efficiency of nanocellulose to enhancing water storage of soil.

Rizwan et al. (2021) reported the most recent research on the synthesis of superabsorbent hydrogels (SAHs) and their agricultural applications. The SAHs are extensively being used as a conditioner for soil and rapid plant growth. A soil conditioner promotes the mechanical properties of soil and facilitates the plant by providing slow nutrient release of fertilizer periodically. The use of SAHS increases the water retention property of all types of soil and has a large swelling index. All these functional properties proved the best solution for the global upcoming water issue with concerning plant growth in the agricultural field. The superabsorbent hydrogels facilitate the growth of plants with limited use of water and fertilizers. This research supported concepts that superabsorbent hydrogels, nanocellulose or any polymers are the efficiency materials for application to agriculture field as soil conditioner. Sine these substances can improve soil properties to be increasing specific surface area, aggregate stability as well as become organic matter into soil.

As the result of this study is similar to pervious researches. They show that nanocellulose can improve physical properties, especially, water retention capacity of sand or coarse-textured soil. Moreover, this result showed more pore-size distribution and decreasing surface evaporation after adding NC. These properties may improve water retain longer in soil and regulating available water supplies for plant. The added content of NC of this study is the same important parameter as previous researches. Base on the result of this study, nanocellulose may be an alternative to rapid solve the drought situation particularly under arid region. However, even nanocellulose is high effective for soil property improvement, but still high cost for agricultural field at the moment. In many regions of Thailand, almost soils are coarse-textured soil as sand-property that low water retention and poor structure. This product would be a solution for this problem. By practicing, nanocellulose may be added into soil and plowing before seedling or planting. In addition, NC can be dissolved with water and spray on soil surface. They need more developments to find out the properly procedure and economic-cost for agricultural field.

Conclusion

This NC product can be used as soil amendment to improve water-holding capacity. The coarse and medium-sand, NC enhances WHC about 50–100 percent. The high content of NC did not affect on WHC of fine-sand but promote aggregation instead. Sand-particle size as well as NC content could be determined factors for improving water-hydraulic property. The optimal content of NC : sand was 1:50 to 1:100 for economical investment. The NC did not only enhance WHC but it improved the water remaining longer also. The same result as soil-textures, coarse-sand particle was significantly affected by high NC ratio to enhanced water storage. On the other hand, fine-sand was slightly affected for water storage by NC but promoted aggregation instead. The NC can change in pore size distribution of fine sand, especially, increasing macropores.

The sand-size affected on WHC as well. In coarse-sand, NC could increase water absorption more than medium and fine-sand. The NC enhanced the fraction of micropores and surface area to absorb water in coarse-sand. Even though NC did not reduce the evaporation rate, but it can maintaining moisture in sand longer than without NC. This NC acts as soil cementing agent to increase the water-storage pores and surface to absorb water. Fine sand, NC promote aggregation that positively increase aeration. As this result and previous researches, NC could be used as soil conditioner to enhanced water retention. Coarse and medium particles, NC could increase water storage and maintain moisture longer. Whereas fine particle, NC could enhance aggregation to be better structure. Which these reasons the NC could reduce the rate of soil erosion as well. The NC might be alternative organic material to increasing water-holding capacity in arid region, solving drought crisis and controlling desertification that widely occurred in many places in the world.

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