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New material for transforming degraded sandy land into productive farmland

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ABSTRACT

China has achieved the most remarkable success in fighting desertification. Unsustainable measures and practices gave rise to continued desertification expansion in some places. Sand land structural consolidation engineering was conducted in Mu Us Sandy Land using physical complementarity between sand particle and clay particle. Degraded sandy land was transformed into productive farmland for developing modern agriculture after soil reconstruction, crop optimization and precision management. Red clay can significantly increase crop yields by improving sandy land structure. Enhanced land productivity, increased land transfer rent and extra wage income provide a stainable and stable increase in households' income for escaping from poverty. Spatial overlap between red clay with sandy land makes red clay as a new available material for sand land consolidation and utilization from China to global scale. China's sandy land structural consolidation engineering and sustainable utilization practices will contribute prescriptions to global desertification fighting and rural poverty alleviation. Regional water resource carrying capacity should be evaluated before engineering popularization.

1. Desertification and fighting

Land is an essential natural resource for humanity survival and prosperity. A quarter of the earth's lands are degraded (Lal et al., 2012). Rapid expansion and unsustainable management is the direct driver of land degradation, undermining the well-being of 3.2 billion people (Pandit et al., 2018). Restoring degraded land is an urgent priority to protect the ecosystem services vital to all life on Earth. United Nations 2030 Agenda for Sustainable Development established the key objective of "Degraded Land Zero Growth". Desertification is a global land degradation problem that averagely 12 million hectares of land are lost every year to desertification (UNCCD, 2015). Desertification affects the peasant sustainable livelihood and rural sustainable development in 169 countries involving all continents. Avoiding, reducing and reversing desertification is crucial to addressing poverty, food security and the loss of world's biodiversity. China faces oversized population living in the drylands that surpasses the ecological carrying. Combating desertification is one of the goals in United Nations' sustainable development program. About 35 % of China's impoverished counties and 30 % poor populations depend directly on ecologically fragile desertification land (Wang and Li, 2019). Residents in desertified areas were simultaneously influenced by environmental degradation and poverty (Cao et al., 2018). As a result, China's government has established many policies and projects to fight desertification during the past decades. Recently, desertification land has been place firmly at China's new policy agenda such as "ecologically-friendly construction" and "cultivated land protection".

Various innovative methods to protect arable land from being degraded and to rejuvenate desert have been effective in fighting against desertification. Some governments, including those in the United States, Canada, Germany and Romani, have used management policy and legislation to encourage desertification land development and conservation. Other countries, such as Israeli, The United Arab Emirates and India, tried to rehabilitate desertification by integrating advanced technology with controlling measures. In Australia, Egypt and Iran, projects to develop industry and promote economic growth have improved the survival and ecological environment. China has always pooled the wisdom and offered some prescriptions in combating desertification with the other countries and regions including government leadership, public communities' participation, scientists support and legal guidance and policy incentives (Bao et al., 2017; Cao et al., 2018). A series of laws and projects was launched, including Three-North Shelterbelt Project, Return Farm and Grazing lands to Natural Forest or Grasslands. China has established national desert monitoring system,

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consisting of 43 research stations from North China to Southeast China (Wang et al., 2013a,b). China's deserts are shrinking by 2424 km^2 annually, compared with an annual expansion of 10,400 km^2 at the end of last century. However, dryland restoration programs cannot match species' water requirements with regional water availability (Bryan et al., 2018). Afforestation have caused a rapid deplete in soil moisture and groundwater (Lu et al., 2016). In addition, some traditional policies and related subsidies didn't create new employments and sustainable livelihood. A vicious cycle between environmental degradation and poverty has generally found after the program (Cao et al., 2018). Desertification has continued to expand in some places due to the failed radical treatment of sandy land structural and unsustainable practices.

Sandy land has poor capability of water and nutrients retention due to scarce clay or silt particles. Too much sand particle makes sandy land loose and sterile. Appropriate sandy land consolidation and utilization measures are texture improvement by exogenous clay or silt addition (Liu et al., 2018). Natural organic matter such as sediment, peat, sapropel and municipal sludge has limited sources and inconvenient transporting. Chemical hydrophilic polymers and viscous paste has disadvantage of higher costs, lower sustainability and secondary pollution (Han et al., 2015). The challenge is not only to find cheap, convenient and natural clay-rich and silt-rich materials but also to develop related engineering, agronomic and management technologies achieving synergy ecological protection and economic development.

2. Sandy land structural consolidation and sustainable utilization

Structural consolidation concept was introduced to improve sandy land from soil particle to profile. Red clay was used to reconstruct aggregate, profile and nutrients of degraded sandy land (Liu et al., 2018). Tertiary red clay deposits widespread distribute surrounding loess plateau and sandy land in northern China (Ding et al., 1998). Red clay is too barren with higher bulk density and thinner soil layer to sustain plants growth. However, Cao et al. (2007) demonstrated that red clay is more suitable for mixed-species plantations than loess in China's loess plateau. But in sandy areas, red clay usually is used for making bricks or road construction with a cheap price of 6 US dollars per cubic meter. Abundantly and cheap red clay is unsuitable for crop roots growth while perfectly solve the sandy land structural defect.

In Mu Us Sandy Land of Northwest China, We used the soil particle complementarity between sand and clay to consolidate sandy land and develop modern agriculture by a series of soil reconstruction, crop optimization and precision management technologies (Fig. 1). Dry mixture of sandy land and red clay at volume ratios of 1:1, 1:2, 1:3 and 1:5 were thoroughly blended into cultivated layer with a thickness of 30 cm. Additional 15 cm red clay was used to build the density layer for water and nutrient conservation. New constructed land has appropriate soil profile, ideal soil structure satisfying plant growth. In order to match crop's physiological demand with new soil ecological suitability, locally maize, potato and soybean were planted on new soil to select the appropriated sandy land structural consolidation engineering. Fertigation techniques were used for precision management and to satisfy the fertilizer and water demand of three crops.

Field results showed that red clay significantly increased the new soil clay ($<$ 0.002 mm) and silt content (0.02-0.002 mm) while decrease the new soil sand content (2-0.02 mm) (Fig. 1). The yields of corn and soybean were significantly higher in the mixture of sandy land and red clay at the volume of 1:3. The higher potato yield was 42,501 kg ha^{-1} in the mixture of sandy land and red clay at the volume of 1:5 (Fig. 1), which is 1.42 times of general potato yield in Northwest China (Fig. 1). We concluded that red clay has much promise and could be very effective to sandy land consolidation.

3. Promotion of sandy land consolidation engineering to rural poverty alleviation

Structural consolidation and modern agricultural development mode was popularized about 4400 ha in Mu Us Sandy Land. In Yulin city, Shaanxi province, 500 households transfer their sandy land with areas of 1467 ha to Dadi agricultural industry after structural consolidation using red clay. Improved productivity of new consolidated land directly brings about increased benefits up to 30,000 yuan ha^{-1} from potato planting. Land transfer rent increases from 150 yuan ha^{-1} of original sterile sandy land to 3000 yuan ha^{-1} of consolidated sandy land. Dadi agriculture industry provides more than 57,000 employment opportunities annually for local households to participate in potato management and harvest. Higher land productivity, increased land transfer rent and extra wage income provide a stainable and stable increase in households' income for escaping from poverty. Therefore, using red cay to transform sandy land into productive farmland can be regarded as a win-win approach suggesting by Cao et al. (2018) that both fights desertification and provides a sustainable livelihood for local residents.

4. Practical potential

We used the red clay distribution areas and soil profile depth to calculate resources storages. Red clay is mainly distributed in northwest China with the total area of 5689.61 km^2 base on China soil database. The average soil profile depth of red clay is about 63.7 m based on 47 published articles (Fig. 2). Total red clay resource storages will reach 76,358 m^3 when we serve the red clay within 50 km of the sand edge as available resources.

In 2015, China's government released the target that more than 50 % of national governable sandy land should be effectively controlled by 2020. It is estimated that red clay resources can consolidate 33.94 $\times 10^4$ km^2 sandy land to plant corn or soybean, or consolidate 38.18 $\times 10^4$ km^2 sandy land to plant potato, which account for 19.72 % and 22.18 % of China's total sandy land area, respectively. New created farmland is mainly distributed in Badain Jaran Desert and south edge of Mu Us and Khorchin Sandy Land, locating in Gansu, Shaanxi and Liaoning Provinces, respectively. According to the estimation from Wang et al. (2019) in Mu Us Sandy Land area, total investments of sandy land structural consolidation engineering are about 74,700 Yuan ha^{-1} and 67,200 Yuan ha^{-1} for planting corn/soybean and potato. Machinery input is the same of 7200 Yuan ha^{-1}. Red clay costs contribute about 90 % to the total engineering inputs. But, gross profit will reach 16,739 Yuan ha^{-1}, 9100 Yuan ha^{-1} and 85,004 Yuan ha^{-1} for corn, soybean and potato harvesting, respectively.

Modernized production technology and reasonable utilize the local available resources can realize both socioecological development and environmental protection (Feng et al., 2019). In the Shennongjia region of China, environment protection was in balance with socioeconomic development as well as satisfying human esthetic needs after establishing ecological corridors strategy in road construction (Cheng et al., 2015). Structural consolidation and modern agriculture development in water-deficient sandification areas should not be done at the cost of water security. Red clay particle can be considered as water pool to retain soil moisture avoiding useless leakage and evaporation. In loess plateau, greater porosity of the red clay can increase rainfall infiltration and decrease soil moisture evaporation which sustains trees to survival under drought (Cao et al., 2007). In Mu Us Sandy Land, about 61 % of water consumption with amounts of 4632 m^3 ha^{-1} in original sandy land was saved by mixing sand with arsenic sandstone (Wang et al., 2013a,b). In our field experiment, drip fertigation technique can precision meet the water demand of crop growth. Preliminary results showed that irrigation water amount is 2293 m^3 ha^{-1}, 1586 m^3 ha^{-1} and 2233 m^3 ha^{-1} for potato, corn and soybean planting, leading to water saving of 70.02 %, 51.02 % and 30.87 %, respectively.

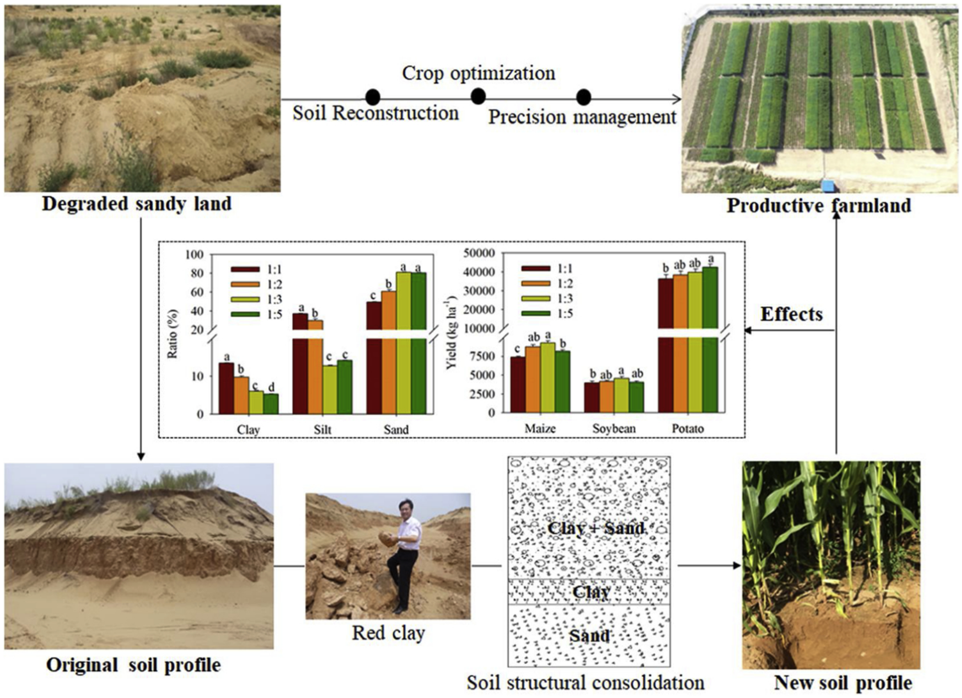

Fig. 1. Frameworks of sandy land structural consolidation engineering.

Furthermore, in southeast edge of Mu Us Sandy Land, precipitation is more than 400 mm based on the meteorological station data. Gradually wetting climate will satisfy the local crop's water requirement (Li et al., 2016). In the dry year, relatively abundant shallow groundwater and surface water resources will provide the guarantee of modern agricultural production.

Deserts cover about one-third of the Earth's land surface area. Addressing desertification is essential to meeting the Millennium Development Goals which aims to ensuring environmental sustainability and eliminate extreme poverty. Red clay had been proven as and effective material to rehabilitate desertification and regain land productivity in specific region. Globally, red clay soil profiles overlap with desertified or sandy land in arid, semi-arid climate. Pan and Peng (2015) summarized that red clay was found in India, Pakistan region of

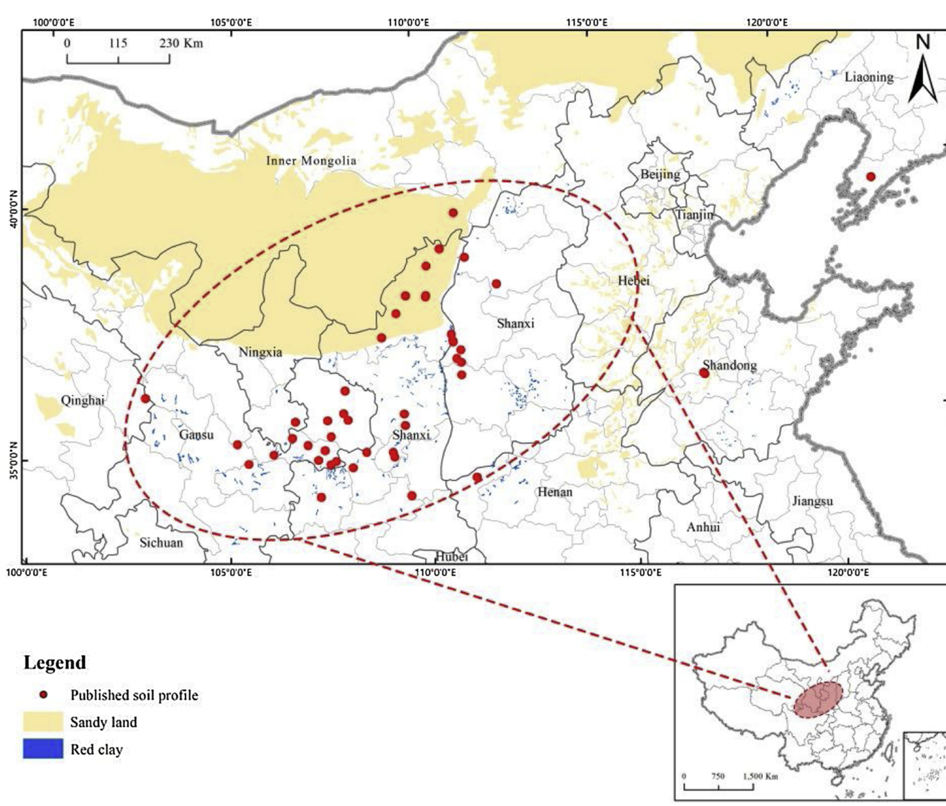

Fig. 2. Red clay resources spatial distribution and published soil profile location.

Thar Desert, Iraq, Jordan regions of Syrian Desert, Egypt, Sudan, Tanzania, Mali regions of Sahara Desert, northwest and south regions of Australian Desert. Red clay offers the material and confidences for the global battle against desertification. Governmental, corporate and social organizations should work together to combat desertification through developing water-saving irrigation, protecting the surface soil and groundwater resources, optimizing the agricultural and animal husbandry structure pattern. China's technology innovation and engineering practice of sandy land structural consolidation and sustainable utilization will contribute prescriptions to make remarkable achievements in fighting desertification and alleviating regional poverty.

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