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Sustainable intensification of China's agroecosystems by conservation agriculture

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A B S T R A C T

Agriculture in China started about 8000 BCE with cultivation of millet and rice. Thus, China's modern agriculture is rooted in a long evolutionary history of agricultural practices. China's population of 211 million in 1700 increased to 295 million in 1800, 400 million in 1900, 1266 million in 2000, and is 1409 million in 2017. Thus, China has to feed 18.5% of the world population on merely 7% of the world's arable land and with even scarcer water resources. Yet, between 1950 and 2017, the grain production in China increased at a faster rate than that of the population. Total grain production (million ton or Tg) was 113 in 1949, 305 in 1970, 462 in 2000, and 603 in 2015. The high agricultural productivity is attributed to high consumption of fertilizers (58.8 Tg in 2015), pesticides (1.81 Tg in 2014), and irrigation (65.7 Mha in 2014). However, the high production is also associated with the severe problems of soil degradation (erosion), water contamination and air pollution. It is estimated that ~40% of China's arable land is degraded to some degree. Thus, there is a strong need for a paradigm shift of sustaining high productivity while restoring quality of natural resources of soil, water and air. In this context, conversion to a system-based conservation agriculture (CA) may be an important strategy of sustainable intensification of agroecosystems for advancing and sustaining high production while restoring soil health, purifying water and air and improving the environment. The CA has been practiced in China since 1990s and was adopted on ~8.0 Mha in 2015. The available literature shows that conversion to CA increases soil organic C (SOC) concentration and stocks mostly in the surface layer while also producing an equivalent agronomic yield. Therefore, a widespread adoption of CA in China would necessitate a deeper understanding of its ecological underpinnings. To be effective, site-specific CA practices must reduce risks of soil erosion under dry land farming, achieve and sustain high productivity, reduce emissions of N_2O and CH_4, sequester SOC, and decrease inputs of fertilizers and pesticides. To be widely accepted, site-specific CA packages must also address the followings: availability of crop residues mulch, techniques of weed control, access to a seed drill, and availability of farm labor. Economically, CA must increase agronomic yield and the farm profit. Being a knowledge-intensive and complex system, there is a strong need to strengthen the extension services, and conduct long-term and farmer-driven research to alleviate specific constraints (e.g., drought, wind and water erosion, nutrient imbalance, weed control).

1. Introduction

China has an ancient agrarian culture. Millet was grown in China around 8000 BCE. Domestication of rice and some farm animals started around 7500 BCE, settled agriculture circa 5000 BCE and Banco village near Xian (Hemudu or matriarch culture) circa 5000-4000 BCE (IBP, 2014; Liu, L. et al., 2013; Liu and Chen, 2012). During the Stone Age, China had several agrarian civilizations such as the Pelligang in Henan; Hemudu in Yuyao and Zhejiang; Hongshan in Liaoning; and three distinct cultures along the Yellow River comprising of Dewerikou (lower), Yangshao (middle) and Mao Ji Yo, Benshan and Machang (upper regions). Stone age culture included the development of some farm tools such as a spade made from stone or animal shoulder bone (Hemudu culture, Underhill & Guoping, 2013) and millstone for husking millet (Pelligang-Cishan culture in North China). Fire and flood management of coastal swamps were basis of the first rice cultivation in east China (Zong et al., 2007). Civilization was established in northern China ~1100 BCE in the Zhou Dynasty, and irrigation was used along the Yellow River around 3000 BCE (Kitova, 2016).

Two revolutionary achievements in China's agriculture made

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circa 476–700 BCE were: (i) iron spade and other tools and the use of farm animals to pull the plow and as beast of burden, and (ii) large scale harnessing of rivers and development of water conservation projects. Important among the water conservation projects were: (i) Dujiang Dam constructed on the Min River in the vicinity of today's Chengdu, Sichuan Province, circa 406-221 BCE, (ii) canal in the State of Zheng in Guanzhong region, today's Shanxi Province, and (iii) linking of two large river systems (Yangtze and Pearl Rivers) by a 2000 km canal in south China. The hydraulic-powered trip hammer was developed in Hahu Dynasty, circa 202 BCE-220 CE (Hsu, 1980; IBP, 2014). Numerous iron tools were developed during the western Han period of 202 BCE to 16 CE. An iron moldboard plow was discovered in Liaoyang Province. Jia Sixie of the Northern Dynasty was the leading agronomist of his era (Lewis, 2009; Li, 2001; Needham & Wang, 2008). His writings “Important Arts for People Welfare” was China's first book on agronomy. The book comprised of 92 chapters in 10 volumes containing 120,000 characters. An agricultural manual prepared by Fan Shengzhi Shu was written during the late Former Han (206 BCE-8 CE) period (Lin, 1994; Liu, Z., 1992; Wu, 1992). The manual provided practical information about intensive agriculture including labor-intensive method of rice paddy farming (Kitova, 2016). China's modern agriculture being rooted in the long history of agricultural evolution over more than 10 millennia, the challenges of modern agriculture must be viewed in the context of the historic evolutionary trajectory.

1.1. Soil and environmental degradation in modern China

China's agronomic and economic achievements since 1980s, unique and unprecedented in human history, have strong environmental footprint. While even the bigger challenges to sustaining food and nutritional security lie ahead, soil and environmental degradation remain to be serious threats to China's sustainable development. Land misuse and soil mismanagement aggravate environmental degradation including those of soil, water, and air (Fig. 1), especially in managed ecosystems: grasslands, forest lands and crop lands. Among several processes and types of soil degradation in China (Fig. 2), accelerated erosion by water is the most severe hazard (Deng & Li, 2016; Smil, 1984). China's grasslands with an area of ~400 million ha and covering >40% of land area, are prone to a wide range of degradation processes(331 Mha or 84% of grasslands) because of over-grazing, improper cultivation, and climate change (Wu, Deng, Yin, & Yuan, 2013). In the semi-arid Bashang area of north China, Zhao, Xiao, Liu, and Li (2005) reported that cultivation of grasslands results in significant soil degradation as manifested by the coarsening of soil texture and depletion of soil organic matter (SOM) and nutrient contents. After 50 years of cultivation, the magnitude of elemental decline in 0–20 cm depth was 73–79% for SOM, 60–70% for total N and 67–68% for total P. As much as 50% of these losses occurred during the first 8 years. There are no reliable estimates of the extent of forest degradation in China (Gao, Skutsch, Drigo, Pacheco, & Masera, 2011). With increase in demand on finite land resources, the forest shrinkage and degradation are increasing especially in the Northeast China (Jiang, Deng, Zhan, & He, 2011). Cropland degradation is the most severe problem in China because of the large population (1.4 billion in 2017; UN, 2017), small total land area (939 million ha or Mha), and a population density of 150 persons/km^2. Thus, 18% of the world population lives on 7.2% of the world's ice-free land area. The arable land is only 11.3% of the total land area of 939 Mha. Thus, heavy demands on a limited land area can aggravate risks of soil and environmental degradation by erosion, salinization, compaction, SOM and nutrient depletion etc. Cropland is also being converted to other competing uses (e.g., urbanization, recreation, industrialization, infrastructure development). Degradation of cropland in North China Plains (Li, Z.H. et al., 2015) has severe consequences not only to food security and

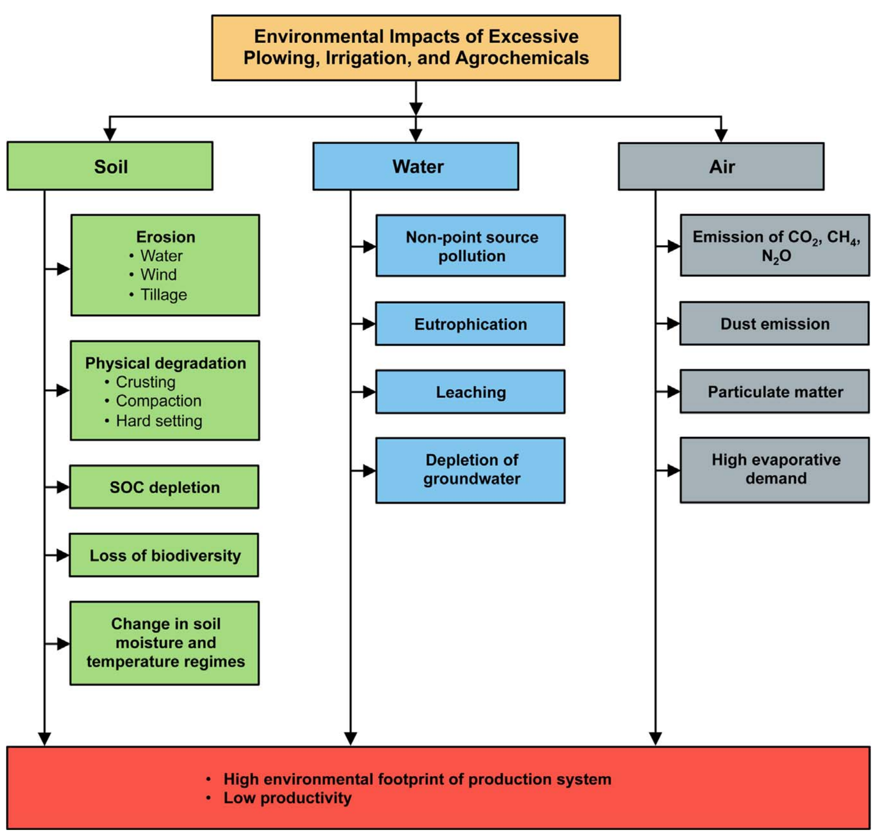

Fig. 1. Adverse impacts of indiscriminant plowing and use of chemicals on soil, water, and air resources.

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