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REVIEW

Air pollution, food production and food security: A review from the perspective of food system

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Abstract

Air pollution negatively impacts food security. This paper reviews the current literature on the relationship between air pollution and food security from the perspective of food system. It highlights that agricultural emissions which substantially contribute to air pollution could happen at every stage along the food supply chain. Meanwhile, air pollution can not only affect plant growth and animal health but also shift market equilibrium of both agro-inputs and outputs in the food supply chain and thereby affect food security indirectly. Furthermore, this study evaluates the effects of agricultural policy and energy policy on food security and air pollution, respectively, and provides an overview of potential policy instruments to reduce air pollution while ensuring food security. Finally, we identify the remaining research and policy issues for further studies, mainly focusing on the study of household's bounded rational behaviors and the issue of rural aging population.

Keywords: air pollution, food production, food security, food chain, bioenergy

1. Introduction

Since the beginning of 20th century, the intensification of agricultural land use and a dramatic rise in yields have gradually taken the place of extensification and become the new engines of agricultural growth (Matson *et al.* 1997; Foley *et al.* 2005). FAO statistics (FAOSTAT, http://faostat3.fao.org/) indicate that during 1961–2014, world population increased by 136%, while the production of grain and meat went up by 188 and 345%, respectively. Apparently, the growth rate of agricultural outputs far overtakes population growth worldwide, and hence human well-being has been significantly enhanced. In the same period, yields of wheat, rice, and maize have rapidly increased by 204, 144, and 189%, respectively. From 1965 to 2004, agricultural intensification avoided an estimate of 18–27 million hectares from being converted to farmland (Stevenson *et al.* 2013).

Different from traditional agriculture, intensive farming relies heavily on industrial agro-inputs, such as synthetic fertilizers, pesticides, and machinery (Pingali 1997; Kimbrell 2002; Woodhouse 2010). FAO statistics show that in 2012, world synthetic nitrogen fertilizer consumption reached 100 million tons, and total agricultural energy consumption peaked at 8 728 petajoules. Although industrial agriculture has successfully fed the world and achieved sustained food surpluses, over-dependence on fossil fuels and intensification have also caused extensive environmental damages. One of the most notable environmental issues is the air pollution. Air pollution in turn could damage

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agricultural production, and shift equilibrium of food markets.

According to the latest report from Intergovernmental Panel on Climate Change (IPCC), Agriculture, Forestry, and Other Land Use (AFOLU) Sector contributes approximately a quarter of global greenhouse gas (GHG) emissions (http://www.ipcc.ch/report/ar5/syr/). This share is expected to rise along with increasing demand for meat products in developing and low-income countries (Garnett 2011; Yu 2015; Hasiner and Yu 2016). Additionally, ammonia (NH_3) emissions, mainly from fertilized land and animal waste (Sheppard *et al.* 2010; Hristov 2011), are currently responsible for 75% of global emissions (FAO 2001). The primary environmental concern with ammonia emissions is formation of particles as a result of atmospheric reactions (Hamaoui-Laguel *et al.* 2014). Compared with other harmful air pollutants, particulate matters (PM) are more lethal (WHO 2009). Nowadays, both in the United States and the European Union, agriculture is viewed as the prime culprit of air pollution (Erisman *et al.* 2007; Bauer *et al.* 2016).

Meanwhile, atmospheric pollution might be adverse to agricultural production in turn. For instance, the toxic air pollutants, such as sulfates, nitrates, dusts, and heavy metals can accumulate in the food chain by diffusion, settling, and precipitation, and consequently harm plants and animals (McCormick 1989; Nagajyoti *et al.* 2010). Global warming, caused by the GHG emissions, is changing the distribution and behavior of species, which would influence agricultural productivity in the long-term (Chen *et al.* 2011; Lobell and Gourdji 2012). Besides, the health effects caused by air pollution would reduce worker productivity (Zivin and Neidell 2012; Chang *et al.* 2016), and thereby threaten food supply indirectly (Sun *et al.* 2017).

FAO predicts that, by 2050, the global population will reach 9.1 billion, which requires at least 70% increase in agricultural production. Specifically, annual cereal production must rise to 3 billion tonnes, and meat production must exceed 200 million tonnes (FAO 2009). Such stress may reinforce the current trends of intensive farming (Matson *et al.* 1997), even at the cost of environmental deterioration (Godfray *et al.* 2010; Tilman *et al.* 2011). Hence, how to mitigate agricultural emissions while ensuring food security is a long-term challenge for both scientists and policymakers.

Agricultural emissions could happen at any point along the food supply chain — production, processing, distribution, and consumption configurations (Aneja *et al.* 2008). The process of air pollutant formation in routine agricultural operations has been well studied (Mosier *et al.* 1998; Sommer and Hutchings 2001; Stehfest and Bouwman 2006). However, ancillary emissions, related to the farming operation, such as emissions from transportation and agro-input manufacturing industries, are usually ignored by researchers, which would underestimate agricultural sector's contributions to air pollution.

Similarly, most existing research related to the impact of air pollution on agriculture only focuses on consequences of air pollution for plant growth (Emberson *et al.* 2003) and animal health (Holgate *et al.* 1999). In fact, air pollution could influence both the quantity and quality of agro-inputs in the food supply chain and thereby affect food security indirectly. For instance, it is evident that air pollution can significantly reduce labor productivity (Zivin and Neidell 2012; Chang *et al.* 2016) and affect outdoor activities (Neidell 2005; Wen *et al.* 2009), and thus influence food supply and demand and shift market equilibrium (Sun *et al.* 2017).

There is, however, no systematic review to date on the linkage between air pollution and food security. This study will draw a full picture of their relationship by reviewing current literature from the view of food supply chain, which could help us find potential opportunities for reducing air pollution while ensuring food security.

2. Air pollution and agriculture in the food chain

Agricultural sector produces considerable amounts of air pollutants from farm to table (Huxham *et al.* 2015), mainly GHG, NH_3, and PM (Erisman *et al.* 2008; Fenger 2009). Meanwhile, at each link, air pollution in turn affects both food supply and demand as well. Fig. 1 illustrates interactions between air pollution and food system. At the farm stage, plants and animals produce massive amounts of air pollutants through the natural process (e.g., excrete), while manufacture and use of agro-inputs make contaminations worse. On the other hand, air pollution can not only directly impact plant growth and animal health, but also indirectly affect effectiveness of agricultural inputs through diffusion, settling, and precipitation and thereby negatively influence farming operation. During food processing and distribution, industrial wastes and vehicle exhaust generate significant amounts of air pollutants, while air pollution might obstruct food supply by reducing worker productivity as well. Finally, because of air pollution, consumers may change their purchase behavior to mitigate health risks. The impacts of air pollution on consumer demand and food supply would shift market equilibrium, and eventually change food price.

In this section, we will briefly review and summarize the main findings from the current literature from the perspective of the food chain.

2.1. Production and inputs

Crop cultivation system In general, GHGs, NH_3, and PM are the primary pollutants emitted from crop cultivation system (Cole *et al.* 1997; Aneja *et al.* 2008). Additionally, the