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Analysis of Agricultural Non-point Source Pollution in Henan Province (China) from the Perspective of Time and Space

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ABSTRACT

Henan is China's most populous agricultural province. Wheat, cotton, oil crops, and other farming and animal husbandry industries rank first in China in terms of output value. The agricultural sector has grown significantly, and rural populations' living standards have greatly improved. The effects of rural urbanization can be seen all over the place. However, the rural economy's rapid growth has resulted in a slew of environmental contamination issues. Chemical fertilizer emissions of chemical oxygen demand (COD) and total nitrogen (TN) have been decreasing for a long time in Henan Province, whereas total phosphorus (TP) emissions are increasing. The usage load of pesticides went high in Zhoukou, Nanyang, Shangqiu, Xinyang, Xinxiang, and Zhumadian. The application of agricultural film was relatively common in Nanyang, Zhoukou, Anyang, Xinyang, Zhumadian, Kaifeng, and Shangqiu. Wheat, corn, and oil-bearing crop stalks are the main sources of crop solid waste in Henan Province, and the solid waste generated by these three crops accounted for 93.96% of the province's total amount. In Zhumadian, Zhoukou, Nanyang, and Shangqiu, there was a lot of crop stalk trash.

INTRODUCTION

Henan Province is a major agricultural province and a major food province in China (Zhang & Shou 2021). The output value of wheat, cotton, oil crops, and other cultivation and animal husbandry industries are among the best in the country. In recent years, the rural economy of Henan has developed rapidly. Some regions have achieved their goal of prosperity. Rural dwellers' living standards have substantially improved, and rural urbanization can be seen everywhere (Yuan et al. 2018, Yan et al. 2021). However, the rural economy's rapid growth has resulted in a slew of environmental contamination issues (Zhang et al. 2020, Zhou et al. 2020), which are mainly manifested in the pollution caused by the large-scale use of pesticides and fertilizers (Zheng et al. 2020, Liu et al. 2017, Gu et al. 2015) and the improper use of crop straws and other solid wastes in agricultural production (Li et al. 2016, Qiu et al. 2016, Zhang et al. 2016).

The key concerns of agricultural non-point source pollution in rural areas of Henan Province are analyzed and studied based on the third agricultural census data and the statistical yearbook of Henan Province over the years. The findings of the study have significant practical implications for the long-term development of rural areas in emerging countries.

MATERIALS AND METHODS

To estimate the agricultural non-point source pollution loads in Henan Province, the agricultural input and output database was established; the database includes the prefecture-level city of Henan Province annual data of the pure consumption of nitrogen, phosphate, and compound fertilizers; the application of pesticide; and the consumption of agricultural film from 2010 to 2019. In addition, the agriculture acreage for the prefecture-level city of Henan Province was included.

RESULTS AND DISCUSSION

Consumption of chemical fertilizers: Fertilization in fields releases large amounts of nitrogen and phosphorus compounds into soil and water, causing soil and water pollution (Xue et al. 2020). According to the national pollution census in 2010, the total nitrogen (TN) and total phosphorus (TP) loads from agricultural non-point sources (AGNPS) accounted respectively for 57.2% and 67.4% of the total emissions in China (Xue et al. 2020). Agricultural chemical fertilizers mainly include nitrogen fertilizer, phosphate fertilizer, potash fertilizer, and compound fertilizer in China. From 2009 to 2019, the trends of scalar fertilization and fertilization in Henan Province are shown in Fig.1.

From 2009 to 2015, the scalar amount of chemical fertilizer application in Henan increased year by year. It was 6,282,700 tons in 2009, but increased to 7,160,900 tons in 2015. From 2016 to 2019, the scalar amount decreased year by year and reduced to 6,667,200 tons in 2019. The amount of fertilizer application was also determined in this work

since the scalar amount of chemical fertilizer application is related to the area of cultivated land, which changed in Henan over the study period. The findings revealed that the fertilizer application pattern in Henan has been steady from 2009 to 2019. From Fig. 2, we can know the fertilizer application load increased year by year from 2009 to 2015. It was 767.42 kg.ha^{-1} in 2009 and increased to 883.42 kg.ha^{-1} in 2015. It began to decline in 2019 and fell to 818.64 kg.ha^{-1} in 2019. Based on the two indicators, since 2016, the amount of fertilizer input to agricultural land in Henan Province has decreased year by year in terms of both total amount and unit intensity indicators.

As for the spatial distribution of agricultural fertilizer application in Henan, the average scalar amount of agricultural fertilizer application in 18 local cities in 2019 was 370,401 tons, and the cities with higher scalar amount levels were Zhoukou (860678 tons), Shangqiu (778648 tons), Nanyang (762346tons), Zhumadian (733984tons), Xinxiang (519743tons), Xinyang (448822tons), and Anyang (432097tons), These seven cities accounted for 68% of the whole agricultural fertilizer scalar amount in Henan. To eliminate the impact of different cultivated land areas on the conversion of agricultural fertilizers, we calculated the fertilizer usage load of 18 local cities in 2019. The results showed that in 2019 the average level of fertilizer usage in 18 local cities was 819.54 kg.ha^{-1} and the cities with a higher amount than the average were Xinxiang (1096.69 kg.ha^{-1}), Shangqiu (1093.58 kg.ha^{-1}), Pingdingshan (1061.52 kg.ha^{-1}), Anyang (1059.25 kg.ha^{-1}), Puyang (1037.08 kg.ha^{-1}), Zhoukou (1003.00 kg.ha^{-1}), Jiaozuo (992.45 kg.ha^{-1}) and Luohe (908.85 kg.ha^{-1}). The city with the highest amount was Xinxiang which reached 1096.69 kg.ha^{-1} and the lowest one was Sanmenxia with 485.68 kg.ha^{-1}. Chemical fertilizer application on agricultural land was extremely diverse depending on the spatial distribution in terms of total volume and intensity.

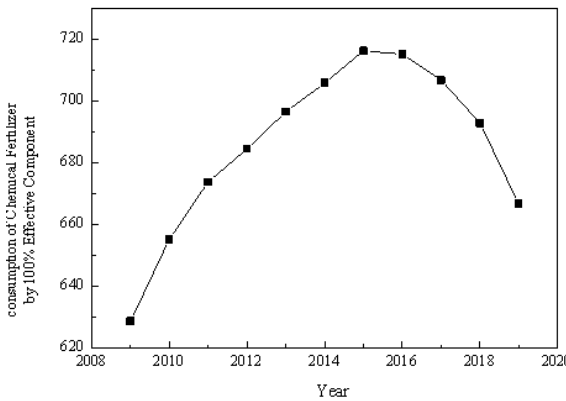

Fig. 1: Consumption of chemical fertilizer by 100% effective component.

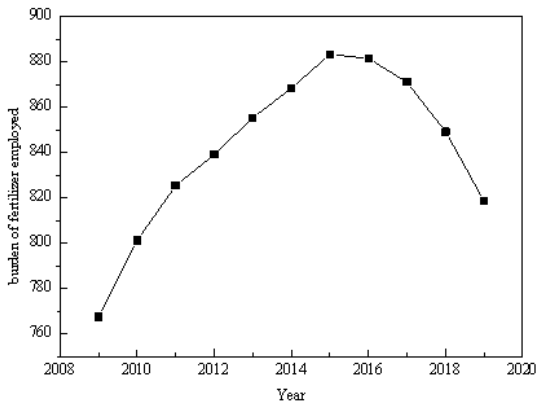

Fig. 2: Load of fertilizer employed.

Chemical fertilizer pollution: The nitrogen fertilizer pollution load in Henan Province was calculated using the following equation, $L(n) = M(n) \times ROC(n)$, Where, L(n) is the nitrogen fertilizer pollution load (kg.ha^{-1}), M(n) is net nitrogenous fertilizer consumption (kg.ha^{-1}), ROC(n) is run-off coefficient of nitrogen fertilizer pollution (Zhang et al. 2020). The phosphorus fertilizer pollution load in Henan Province was calculated using the following equation, $L(p) = M(p) \times ROC(p) \times 43.33$, Where, L(p) is the phosphorus fertilizer pollution load (kg.ha^{-1}), M(p) is net phosphorus fertilizer consumption (kg.ha^{-1}), ROC(p) is the loss coefficient of phosphorus fertilizer pollution (Zhang et al. 2020).

The pollution loads of nitrogen fertilizer and phosphate fertilizer were calculated in 18 local cities in Henan in 2019. The 8 cities with higher nitrogen fertilizer pollution load than the average were Zhoukou, Nanyang, Xinyang, Shangqiu, Xinxiang, Zhumadian, Anyang, and Kaifeng in the order from high to low, accounting for 74.55%. Meanwhile, the 7 cities where the phosphate fertilizer pollution load exceeded the average were Zhoukou, Nanyang, Shangqiu, Zhumadian, Xinyang, Xinxiang and Kaifeng, accounting for 72.08%.

The CODTN emissions generated by fertilizer application in Henan Province are decreasing, whereas the TP emissions are growing, according to the analysis. Fertilizer TN emissions account for around 37% of agricultural source TN emissions. Fertilizer TP emissions account for roughly 36% of agricultural source TP emissions. CODTN and TP emissions are high in Puyang, Anyang, Shangqiu, Xuchang, Kaifeng, and other northeast Henan plain areas, but emissions are low in the southern hilly mountain area, Xinyang, and Nanyang. This phenomenon may be caused by the following aspects: first, the cultivated land resources and population density of southern hilly and mountainous areas are smaller than a plain area; second, the surface water resources of southern hilly and mountainous area are rich, the threat to

local water resources caused by farmland fertilizer source pollution is small. Nanyang, Shangqiu, Xinyang, Zhoukou, and Kaifeng account for almost 60% of the total quantity of agriculture pollution emissions in Henan Province.

Consumption of pesticides and their environmental effects: Pesticides play an important role in increasing productivity, reducing crop loss, controlling disease vectors, ensuring the provision of adequate healthy food, and reducing the labor, fuel, and machinery needed for crop protection activities. China consumes around 43% of global pesticides on less than 9% of global cropland. The average intensity of pesticide use per unit of cropland in China is 13.1 kg per hectare, versus 3.7 kg per hectare in Asia, and 2.6 kg per hectare worldwide (Zhu & Wang 2021). While agricultural pesticides are an important tool in agriculture and other industries, their widespread use poses a significant environmental threat due to their toxic effects and bioaccumulation tendencies in non-target organisms (Sahin & Karpuzcu 2020). Pesticides are frequently linked to risks to soil health, ecosystem function, and human safety (Yang et al. 2021). China is the largest agricultural country in the world (Kuang et al. 2020), and the average amount of pesticides used per hectare is about 1.5 to 4 times as much as the world average. Pesticides can go into surface water through surface runoff, soil erosion, spray drift, drainage, and leaching. Henan Province is one of the regions with the highest population density, developed agriculture, and the fastest growth in national economic output and per capita income in China. The main pesticides used in agricultural production in Henan Province are dichlorvos, trichlorfon, omethoate, parathion, parathion methyl, methamidophos, and other organophosphates and carbamate mushrooms such as carbaryl, as well as packs pyrethroids such as fenvalerate and cypermethrin. The utilization rate of pesticides sprayed on crops is about 20% ~30%, and the other 70% ~80% are lost to non-target crops, soil, or waters. The residual pesticides in the soil environment of Henan Province mainly include atrazine, pentachlorophenol, malathion, DDT and glyphosate.

Figs. 3 and 4 show that the amount of pesticide applied in Henan Province increased from 121,400 to 130,100 tonnes from 2009 to 2013, then declined from 129,900 to 107,200 tonnes from 2014 to 2019. From the viewpoint of the intensity index of pesticide application per cultivated land unit, it increased yearly in 2009-2014, from 14.82 kg.ha^{-1} to 15.99 kg.ha^{-1}, and decreased year by year from 2015 to 2019, from 15.88 kg.ha^{-1} to 13.17 kg.ha^{-1}. The results showed that pesticide application in Henan has begun to drop and stabilize in recent years, both in terms of total amount and intensity index, and agricultural production consumption has decreased.

From the spatial distribution of pesticide usage in Henan, the average usage in 18 provincial cities in 2019 was 5,957 tons. Cities with amounts higher than average were Zhoukou (18192), Nanyang (14620), Shangqiu (11476), Xinyang (10371), Xinxiang (8309), and Zhumadian (7613), accounting for 65.82%. In 2019, the average pesticide usage per unit cultivated area in 18 cities was 12.60 tons/1000 hectares. The above-average cities were Zhoukou (21.20), Jiaozuo (18.83), Xinxiang (17.53) and Shangqiu (16.12), Sanmenxia (14.13), Nanyang (13.87), and Anyang (13.81).

Consumption of agricultural mulch film and its environmental effects: Agricultural mulch film is widely used in agriculture for improving agricultural production (Li et al. 2021, 2020), but it is also the main pollution source of agricultural non-point source pollution in Henan Province. Agricultural mulch film is a synthetic polymer compound material, which will stay in the soil for a long time if it is not cleaned or picked up in agricultural production. In recent decades, with the expansion of global mulch film consumption, the use of agricultural mulch film has also increased

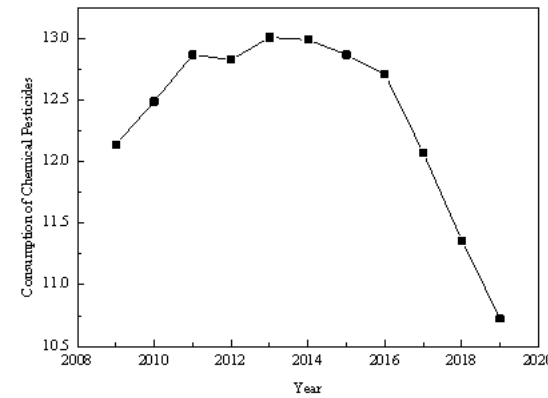

Fig. 3: Consumption of chemical pesticides.

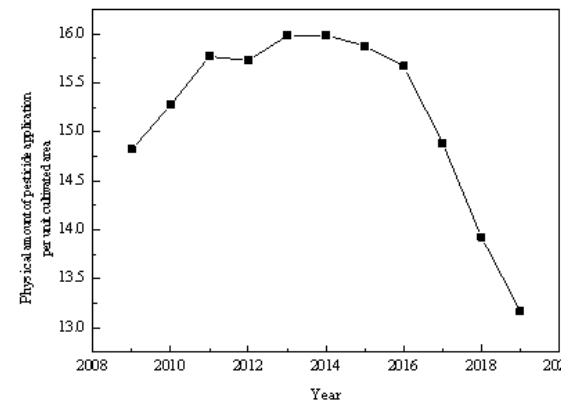

Fig. 4: Physical amount of pesticide application per unit cultivated area.

yearly in China. Debris is likely to remain in the soil due to the thin mulch film's fragility. The mulch is primarily made of polyvinyl chloride, which is difficult to decompose and recycle (Liu et al. 2019). The remaining mulch film in the soil degrades the soil structure and alters the normal movement and distribution of water and nutrients (Liu et al. 2019). Currently, the agricultural mulch film generally used in Henan Province is an ultra-thin film with a thickness of less than 0.008 mm, which has poor ductility, wear resistance, and a short period of use. After being fragmented, it will remain in the soil and extremely difficult to clean.

There is little variation in the average dosage of agricultural mulch film for different crops, and the average dosage of agricultural mulch film for tobacco and watermelon 45 $kg.hm^{-2}$, the average dosage of agricultural mulch film for peanuts is 33.75 $kg.hm^{-2}$, and the average dosage of agricultural mulch film for garlic is 37.5 $kg.hm^{-2}$. The total residue of agricultural mulch film in the cultivated soil is 8.19～17.60 $kg.hm^{-2}$ in Henan Province, with an average of 0.10 $kg.hm^{-2}$. The residual membrane bigger than 100 cm^2 is overwhelming, accounting for 71.9% on average, 20~100 m^2 accounting for 19.2%; 2~20 cm^2 being 7.3%, and debris less than 2 cm^2 being only 1.6%. The residual mulch film in the soil has a large molecular mass and stable performance and, it can stay in the soil and cannot decompose under natural conditions for a long time. The residual mulch film poses a great threat to the soil environment, agricultural production, ecological environment, livestock, and human health, especially to soil and crop growth and development.

Fig. 5 shows the amount of agricultural mulch film used in Henan Province from 2009 to 2016. It can be seen that the usage continues to rise, with the minimum usage of 141,400 tons and maximum usage of 163,100 tons in 2013. From 2017 to 2019, agricultural mulch film usage was declining year by year. From 157,300 tons it fell to 150,800 tons and tended to be stabilized. As to the plastic film usage, during 2019 in the 18 local cities, Nanyang (16.78), Zhoukou (12.83), Anyang (12.05), Xinyang (9.26), Zhumadian (8.35), Kaifeng (8.32), and Shangqiu (8.02) accounted for respectively more than 8% of the total agricultural mulch film usage. These 7 cities accounted for 75.61% in total.

The Yield of agricultural straw and its environmental effects: Agricultural straw is an important byproduct of agricultural systems. With the continuous and active support of Chinese authority to modern agriculture, China's grain acreage and production are gradually increasing, and the amount of crops straw is also increasing yearly. Agricultural straws' functions can be broadly split into three categories: The first is that straw can be utilized as a source of nourishment and as a feed and fertilizer (Wang et al. 2021, Zhang et al. 2021). The second is energy, which can be employed in an industrial project because of its biomass (Yang et al. 2021). Straw can be utilized as a raw material for technical reasons as the third function (Rojas et al. 2019). China offers some policies and financial supports for the comprehensive use of straw (Zou et al. 2020). However, due to various restrictions, 60% of straw resource processing is effectively used as fertilizers, feed, and raw materials, while 40% of the processing is still not used effectively or even discarded at will, which may cause environmental pollution.

Open burning is a prevalent phenomenon during harvest seasons in certain areas of Indoor burning for energy has been regarded to cause health difficulties, particularly lung cancer as well as cardiovascular and respiratory disorders, in Henan Province, generating significant air pollution (Sun et al. 2020). The main characteristic of grain cultivation in Henan Province is numerous in crop variety with large quantities, but at the same time, it faces the big problem of straw processing. The total amount of crop stalk resources in Henan Province can be estimated based on the amount of crop production, and the estimation method is as follows, $S = \sum_{j=1}^{k} s_j d_j$, where S is the number of straw resources, s_j is the yield of a certain crop, and d_j is the grass and valley of a certain crop, as shown in Table 1. The estimation of straw production in Henan Province in 2019 is shown in Table 2.

From the calculated proportion of straw stalk in the above table, the main sources of crop straw in Henan are wheat, corn, and oilseeds, which produce 93.96% of the total straw. We estimated the straw stalk output ratio from the production of major crops in each city in 2019. According to the findings, the cities with the highest ratios were Zhumadian (13.48%), Zhoukou (13.17%), Nanyang (12.22%), and Shangqiu (10.87%), accounting for 49.74 per cent of the total. The rate of exploitation of straw resources is low (less than 60%), while the possibility of resource utilization is great.

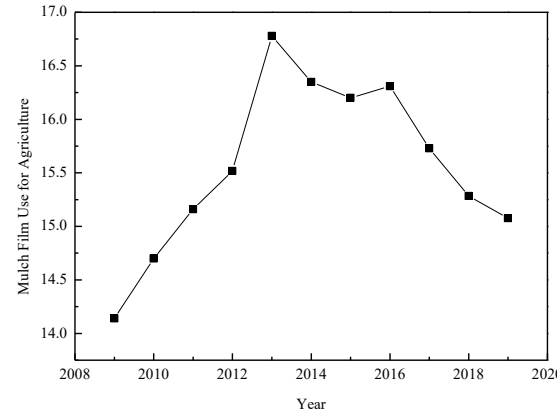

Fig. 5: The amount of agriculture mulch film.

Table 1: Grain-straw ratio.

grain-straw ratio		
paddy 1.0	wheat 1.4	corn 2.0
beans 1.5	cotton 3.0	potato 0.5
bast fiber crop 1.0	oilcrops 2.0	carbohydrate crop 0.1

Table 2: Henan Province's straw production in 2019 ($\times 10^7$ kg).

	Paddy	Wheat	Corn	Beans	Cotton	Potato	Hemp	Oil	Carbohydrate
Yield	512.50	3741.77	2247.37	102.00	2.71	64.50	1.94	645.45	11.93
Straw	512.50	5238.48	4494.74	153.00	8.13	32.25	1.94	1290.90	1.19
Percentage	4.37	44.65	38.31	1.30	0.07	0.27	0.02	11.00	0.01

CONCLUSION

In the last decades, agricultural non-point source pollution is attracting more and more attention in Henan Province, China, due to the rapid development of agriculture there. This study analyses the agricultural non-point source pollution from 2008 to 2019. The total phosphorus loads showed an increasing trend; The chemical oxygen demand, total nitrogen, and total phosphorus pollution loads showed a decreasing trend. The pesticide use load of Zhoukou, Nanyang, Shangqiu, Xinyang, Xinxiang, and Zhumadian cities were higher in Henan; the plastic film use intensity of Nanyang, Zhoukou, Anyang, Xinyang, Zhumadian, Kaifeng, and Shangqiu was higher; the crop waste discharge amount of Zhumadian, Zhoukou, Nanyang and Shangqiu cities were higher. Due to the development of national policies and agricultural technology, in addition to total phosphorus pollution, the farmland non-point source pollution load is decreasing in Henan Province year by year.

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