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Original Research

An Examination of Regional Variations in Pesticide Usage and Grain Yield in China Before and After the Double Reduction Policy's Adoption

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Abstract

Prior to and following the implementation of the "double reduction" strategy in China, regional variations in pesticide usage and grain yield were examined using the Theil index, spatial autocorrelation analysis, and elasticity coefficient. The findings revealed an increasing tendency in eastern China and a declining trend in western China for intra-regional variances. The increased grain yield in the eastern and central regions was less affected by the double reduction program. The program, however, had had a significant impact on the rise in grain yield in the west. In comparison to the prior year, pesticide usage in China exhibited a significant decline with the adoption of the double reduction program (2015-2019). At the global level, there was a positive spatial association between the usage of pesticides and grain yield. The majority of regions left the "high-high" and "high-low" concentration zones for pesticide usage between 2015 and 2019. A "double growth zone" was what distinguishes the relationship between pesticide usage and grain yield in China from 2010 to 2014. The "other factors influence zone" predominated by 2015–2019. In keeping with the performance of the national pesticide usage intensity, the Eastern, Central, and Northeastern regions' pesticide usage intensity decreased generally between 2010 and 2014. In the western region, there was an increase in pesticide usage intensity. In comparison to the nation as a whole, all four regions exhibited a declining trend in pesticide usage intensity from 2015 to 2019. Together, the strategies for reducing the use of pesticides in all regions had been better carried out until 2019.

Keywords: double reduction policy, pesticide usage, grain yield, regional difference

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Introduction

Food security has an impact on a nation's political stability and economic progress [1]. The usage of fertilizers and pesticides is essential to China's ability to feed its people [2]. The ecological and environmental issues brought on by the widespread use of pesticides and fertilizers are gaining prominence even as food production is constantly rising [3, 4]. Due their unique characteristics, pesticides are more immediately damaging to the ecology than chemical fertilizers [5]. The considerable impact that excessive pesticide usage has had on biodiversity is difficult to undo in the short run [6]. Pesticide consumption in China was 7.65 x 105t in 1991, according to data from the National Bureau of Statistics of China (https://data.stats.gov.cn), and it has grown yearly since then. In 2015, China put forth the, which asks for the implementation of reduced pesticide usage [7]. Numerous academics have done yearly research on the general characteristics or impacts of reductions in fertilizer and pesticide consumption in China since the "double reduction" policy's introduction [8-12]. By 2015, China was still applying more fertilizer than the year before, but the increase was only 0.4%, while the number of insecticides used fell by 1.3%. Both the use of pesticides and fertilizers increased negatively between 2016 and 2018. It is evident that China has fully implemented its double reduction policy. With 1.4 billion people, though, the demand for food is even more of a problem [13-15]. It will not be worth the loss if the double reduction approach causes a decline in grain yield. Thus, data on pesticide usage and grain yield in China were gathered for this study for the five years prior to and the five years following the introduction of the double reduction strategy. For 31 Chinese provincial administrative regions, the relationship between pesticide usage and grain yield was examined. This study seeks to analyze the efficacy of reducing pesticide usage in various regions and to give a reference for preserving national food security and ecological safety.

Data and Methods

Data Sources

China's 31 provincial administrative regions were used as the research unit in this study. Due to the lack of data, Hong Kong, Macau, and Taiwan Province were not considered in this study. The study period spans the five years prior to the implementation of the "double reduction" policy (2010-2014) and the five years following (2015-2019). The China Statistical Yearbook 2010-2019 contains information about the country's use of pesticides and grain yield. The following formula was used to adjust pesticide consumption to the quantity of pesticides used in the grain yield process in order to assure a more precise assessment of pesticide usage.

$$F_m = F \times \frac{S_m}{S}$$

Where, F_m: Pesticide usage in grain yield, F: total crop pesticide usage, S_m: area of grain crops sown, S: total sown area of crop.

Research Methods

A Gauge of Geographical Variance in Grain Yield and Pesticide Usage

Four major zones – the eastern, western, central, and northeastern regions – were divided based on the total disparity between pesticide usage and grain yield in China. Beijing, Tianjin, Hebei, Jiangsu, Zhejiang, Shanghai, Fujian, Shandong, Guangdong, and Hainan are all located in the eastern area. Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan are all part of the central area. Inner Mongolia, Sichuan, Chongqing, Guizhou, Yunnan, Guangxi, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang are all parts of the western area. Liaoning, Jilin, and Heilongjiang are all in the northeast. Theil index values that are higher indicate greater regional heterogeneity in grain yield and pesticide usage. Theil index was determined as:

$$T_{IZD} = \sum_{i=1}^{n_m} T_i \ln\left(n_m \frac{T_i}{T_m}\right) + \sum_{i=1}^{n_b} T_i \ln\left(n_b \frac{T_i}{T_b}\right) + \sum_{i=1}^{n_s} T_i \ln\left(n_s \frac{T_i}{T_s}\right) + \sum_{i=1}^{n_d} T_i \ln\left(n_d \frac{T_i}{T_d}\right)$$

Where, T_{IZD}: Differences within the four zones, n: Number of provincial districts, n_m, n_b, n_s, n_d: Number of provincial districts in the Eastern, Western, Central and North Eastern regions, T_i: Ratio of pesticide usage (grain yield) in provincial districts to national total, T_m, T_b, T_s, T_d: Ratio of pesticide usage (grain yield) in the four major zones to the national total.

Elasticity Coefficient

Using the elasticity coefficient, the relationship between pesticide usage and grain yield was examined. The following is how the elasticity coefficient was determined:

$$K_t = \frac{\Delta M_t}{\Delta P_t} = \left(\frac{M_t}{M_{t-1}} - 1\right) / \left(\frac{P_t}{P_{t-1}} - 1\right)$$

Where, K_t: elasticity coefficient, t: year, ΔM_t, ΔP_t: Rate of change in grain yield and pesticide usage at the provincial level, M: Grain yield, P: Pesticide usage. The significance of the changes in the elements of the formula was detailed in Table 1.

Table 1 The significance of the changes in the elements of the formula.

Area type	Changes of the elements
Double enrichment area	$K_t>0, \Delta P_t>0$
Double reduction area	$K_t>0, \Delta P_t<0$
Pesticide overdose area	$K_t<0, \Delta P_t>0$
Other factors affecting area	$K_t<0, \Delta P_t<0$

Analysis of Spatial Autocorrelation

If there is a substantial correlation between observations of a spatial variable and observations at its adjacent spatial points, this is what spatial autocorrelation analysis looks for [16]. Local and global spatial autocorrelation are both a part of it.

(1) Spatial Autocorrelation Globally

Prior to and following the introduction of the "double reduction" policy, the global spatial autocorrelation was employed to reflect the overall distribution of pesticide consumption and grain yield statistics in China [17]. It was calculated using the following formula using the Moran's I index:

$$I=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\right)\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

Where, I: Global Moran's I statistics, n: Number of provincial districts, $x_i(x_j)$: Pesticide usage (grain yield) in the $i(j)$ the provincial administrative unit $\bar{x}$: Average of pesticide usage (grain yield) of provincial districts, W_{ij}: adjacent weights. I takes values in the range [-1,1]. When I is greater than 0 it means positive correlation, less than 0 means negative correlation and equal to 0 means no correlation. W_{ij} is a binary variable reflecting the proximity of two provinces, with proximity being 1 and non-proximity being 0. Moran's I statistic was obtained according to this formula and then tested for significance. The variance of Moran's I statistic was calculated by the following formula:

$$\mathrm{var}_n(I)=\frac{\left\{\left[n(n^2-3n+3)S_1-nS_2+3S_0^2\right]-\left[k\left((n^2-n)S_1-2nS_2+6S_0^2\right)\right]\right\}}{(n-1)(n-2)(n-3)S_0^2}-E_n(I)^2$$

Where, $E_n(I)=\frac{-1}{n-1}$, it is the expectation of Moran's I, $S_0=\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}$, $S_1=\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left(W_{ij}+W_{ji}\right)^2$, $S_2=\sum_{i=1}^{n}(W_{i\cdot}+W_{\cdot i})^2$, $\mathrm{k}=\frac{\sum_{i=1}^{n}(x_i-\bar{x})^4/n}{\left(\sum_{i=1}^{n}(x_i-\bar{x})^2/n\right)^2}$. The standard deviation of Moran's I autocorrelation coefficient was calculated by the following formula:

$$SD_n=\sqrt{\mathrm{var}_n(I)}$$

Determine whether n regions were significantly spatially correlated by constructing the statistic Z under random distribution conditions. The calculation formula of Z was as follows:

$$\mathrm{Z}=\frac{I-E_n(I)}{SD_n}$$

(2) Autocorrelation in Localized Space

Using local spatial autocorrelation, it is possible to determine the size and importance of spatial variances in pesticide usage (grain yield) between one provincial administrative unit and its surrounding provinces. The Morran's I statistic for the area was used to measure it. The local Morran's I statistic is used to determine the local spatial distribution of pesticide usage (grain yield) in terms of dispersion by plotting LISA agglomerates. This is how the local Morran's I statistic was determined:

$$I_i=Z_i\sum_{j=1}^{n}W_{ij}Z_j$$

Where, $Z_i(Z_j)$: Deviation of pesticide usage (grain yield) from the national average for the $i(j)$: the provincial administrative unit, W_{ij}: Standardized spatial weighting matrix. At the P<0.05 level of significance, $I_i>0$ indicated a positive correlation, with similar values clustering in neighboring provinces. $I_i<0$ means there was a negative correlation and neighboring provinces were not clustered with similar values.

Image Processing

Folding Line Charts were plotted by Origin pro2021 software. The geostatistical images were drawn using Adobe Illustrator 2022 software.

Results and Discussion

Variations in Pesticide Usage and Grain Yield by Region

Large disparities were seen in the changes in the intra-regional variation in pesticide consumption by region from 2010 to 2019 (Fig. 1a). Over the years 2010 to 2019, the disparity in pesticide consumption between the Northeast and Central areas had remained largely steady. The Eastern region's intra-regional variation has a cyclical increase trend, with the Theil index rising by 23.36%. Theil Index growth of 13.37% in the West indicated a modest overall increase in intra-regional variance. The study interval was divided between the time before (2010-2014) and after (2015-2019) the implementation of the "double reduction" strategy, using 2015 as the node. The Eastern and Western areas exhibit the most substantial intra-regional diversity. Following the implementation of the "double reduction" strategy, the intra-regional variation in the eastern

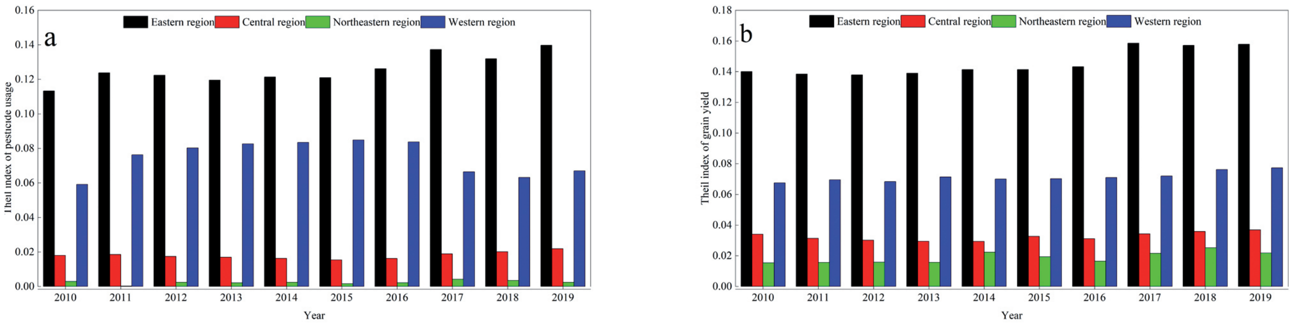

Fig. 1. Regional differences in pesticide usage and grain yield in China from 2010 to 2019.

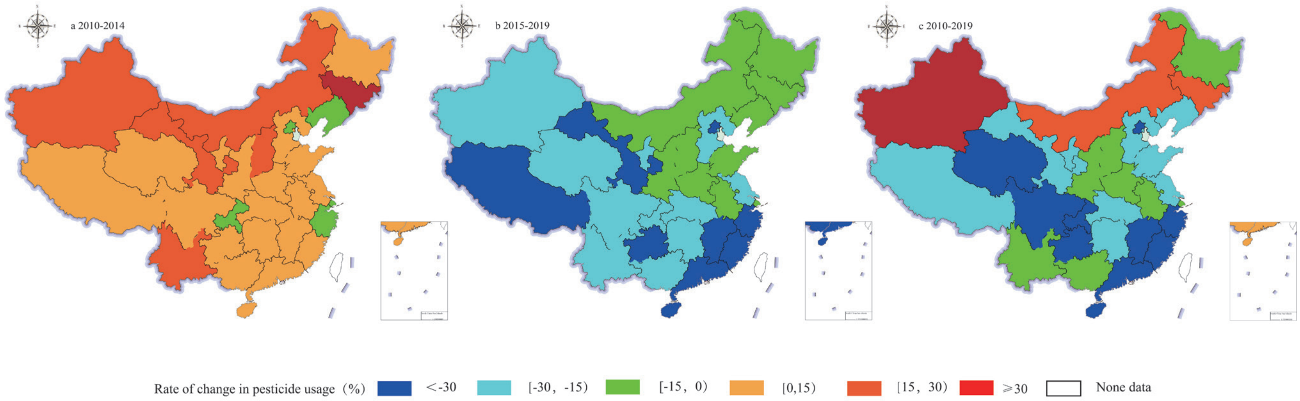

Fig. 2. Trends in pesticide usage in China from 2010 to 2019.

region displayed a more marked increasing trend than the prior era. Following the implementation of the "double reduction" policy, there were much less intra-regional differences in the western area than there had been in the preceding time.

The four main areas' grain yields between 2010 and 2019 show considerable intra-regional variances. All, however, revealed a little increasing tendency (Fig. 1b). The Northeastern region saw the largest increase in intra-regional variation, as measured by the Theil Index, which increased by 41.39%. With an increase in the Theil Index of 8.49%, the Central area experienced the least increase in intra-regional variance. All four regions' intra-regional variation is rising, and from 2015 to 2019, the Theil Index will stay between 10% and 13%. The Northeastern region led the four major regions in terms of grain yield growth before and after the "double reduction" policy was put in place (Table 2), with increases of 19.83% and 15.35%, respectively. Grain yield growth in the eastern and central areas before and after the "double reduction" policy's implementation varied just marginally. In the Western area, grain yield increased by 11.93% in 2014 compared to 2010, but only by 2.92% in 2019 compared to 2015.

Changes in the Temporal and Spatial Distribution of Pesticide Usage

In most provincial governments across the nation, pesticide usage was still rising sharply prior to the implementation of the "double reduction" program (Fig. 2a). The only provinces with a declining tendency in pesticide usage were Liaoning, Beijing, Chongqing, Zhejiang, and Shanghai. From a regional standpoint (Table 2), the use of pesticides in the eastern and central regions has shown a slight decline, whereas the northeastern and western regions continue to show a significant increase, with the northeastern region's use of pesticides increasing by 11.40% and the western region's use of pesticides increasing by 19.97% in 2014 compared to 2010. The highest decline, of 24.45%, was in the Eastern area. Only Xinjiang, Inner Mongolia, and Jilin showed continued growth in pesticide usage in 2019 when compared to 2010 when looking at the rate of change in pesticide usage from 2010 to 2019 (Figure 2c). The remaining provincial districts displayed a fixed level of decline. When compared to 2010, the use of pesticides decreased in all four regions to varied degrees in 2019. (Table 2). The Eastern region had a decrease of 29.04%, the Central region a decrease of 23.21%, the Northeast region a decrease of 11.77%, and the Western region a decrease of 5.03%.

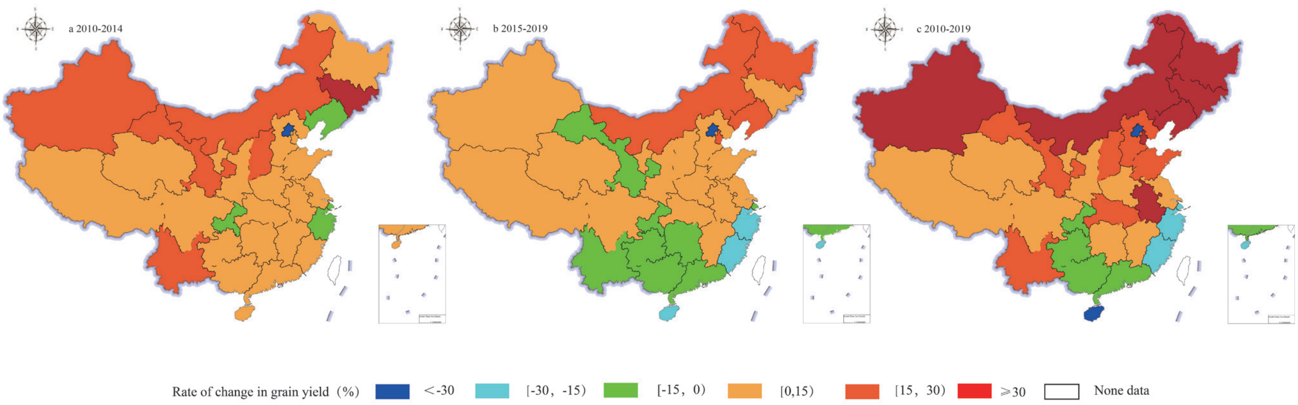

Fig. 3. Trends in grain yield in China from 2010 to 2019.

Changes in the Temporal and Spatial Distribution of Grain Yield

Five provincial administrations had reductions in grain yield prior to the "double reduction" strategy due to a number of historical, economic, and cultural issues (Fig. 3a). Since the implementation of the "double reduction" policy, this number has doubled. However, from 2010 to 2014, all four of the key areas displayed various degrees of regional grain yield growth. For example, the Northeast reported the highest growth rate in grain yield, at 19.83%. The grain yields in the four regions increased from 2015 to 2019 as well. However, compared to before the "double reduction" strategy was implemented, the growth was around 3% lower. The Northeast continued to see the biggest growth in grain yield, at 15.35%. (Table 2). Nine provincial administrations experienced a decrease in grain yield from 2010 to 2019 when examining the rate of change in grain yield by region (Fig. 3c). The majority of them were gathered around the Yangtze River's southern bank. In 2019 compared to 2010, grain yield increased in all four regions to varied degrees (Table 2). The growth rates were as follows: 12.63% in the east, 19.42% in the center, 43.55% in the northeast, and 17.64% in the west.

Characteristics of the Spatial and Temporal Distribution of Pesticide Usage and Grain Yield

Analysis of the Global Spatial Autocorrelation Between Grain Yield and Pesticide Usage

2015 saw the creation by China of the "Zero Growth Action Plan for Pesticide usage by 2020." Therefore, 2015 might be considered the year that China's formal program to reduce pesticide application began. Pesticide usage and grain yield by Chinese province administrative regions in 2010, 2015, and 2019 were analyzed globally spatially using Moran's I statistics. This served as a representation of China's overall high and low concentration of pesticide consumption. The worldwide Moran's I statistic for the three time points for pesticide usage and grain yield passed the test at the 0.05 level of significance, as shown

Table 2. Changes in pesticide usage and grain yield by region in China, 2010-2019.

Year	Pesticide usage/10^4t				Grain yield/10^4t			
	Eastern	Central	Western	Northeast	Eastern	Central	Western	Northeast
2010	62.75	63.29	18.60	31.19	13870.00	16720.70	9620.70	14436.40
2011	63.15	63.40	18.02	34.14	14315.70	17251.70	10777.10	14776.50
2012	61.82	63.77	19.08	35.92	14553.40	17734.90	11175.00	15494.70
2013	61.24	62.98	20.09	36.48	14606.40	17849.20	11750.70	15987.70
2014	60.18	62.01	20.72	37.42	14768.10	18247.90	11528.90	16157.70
2015	58.94	60.77	20.51	38.07	14949.60	18719.70	11973.50	16501.00
2016	56.93	59.17	19.73	38.22	14917.40	18327.90	11876.30	16503.60
2017	54.50	56.22	19.70	35.10	15581.50	20040.40	13895.00	16743.50
2018	47.87	52.90	18.03	31.58	15466.50	20089.70	13331.90	16901.00
2019	44.53	48.60	16.41	29.62	15622.10	19968.50	13810.90	16982.80

Table 3. Global spatial autocorrelation analysis of pesticide usage and grain yield.

Index	Moran's I	E (I)	Variance	Z-statistic	P-value
Pesticide usage in 2010	0.376	-0.033	0.014	3.459	0.001
Grain yield in 2010	0.242	-0.033	0.013	2.372	0.018
Pesticide usage in 2015	0.287	-0.033	0.014	2.702	0.007
Grain yield in 2015	0.262	-0.033	0.013	2.547	0.011
Pesticide usage in 2019	0.365	-0.033	0.014	3.388	0.001
Grain yield in 2019	0.300	-0.033	0.013	2.892	0.004

in Table 3. All six indicators had Moran's I statistics that were greater than 0, indicating that there is a positive spatial association between pesticide usage and grain yield on a worldwide scale. This suggested that, globally, there was a positive geographical association between the use of pesticides and grain yield. All six indicators had variances that were nearly zero, demonstrating the great level of smoothness between the variables.

Analysis of the Local Spatial Autocorrelation Between Grain Yield and Pesticide Usage

Grain yield and local spatial autocorrelation of pesticide application in 2010, 2015, and 2019. LISA clustering maps with local spatial autocorrelation are created based on the significance of the local Moran's I statistic (Figs 4 and 5). Local spatial autocorrelation significance test visual representation of spatial agglomeration traits. For statistically significant 'high-high' agglomerations, they can be deemed to have a high positive proximity effect. They have a negative impact on nearby provincial areas' high rates of food production or pesticide usage. It can be said that "low-low" agglomerations that are statistically significant have a strong adverse effect of proximity. In nearby provincial districts, they maintain modest levels of pesticide usage or food production. There is a region where the favorable and unfavorable effects of proximity meet for the statistically significant "high-low" and "low-high" agglomerations.

In 2010, Shandong, Henan, Anhui, Jiangxi, Hunan, and the other five provincial administrative regions had a "high - high" concentration of pesticide usage. Sichuan and Gansu were the only two provincial administrative regions with "high-low" clustering; the others failed the significance test (p 0.05). (Fig. 4a). Four provincial administrative regions, including Shandong, Henan, Anhui, and Jiangxi, had "high" pesticide consumption in 2015. Sichuan and Gansu were the only provincial administrations having "high-low" clusters; all other administrations failed the significance test ($p<0.05$). (Fig. 4b).2019 saw a "high - high" concentration of pesticide usage in three of the administrative regions of the provinces, including Shandong, Henan, and Anhui. Sichuan, Gansu, and Xinjiang were the three provincial administrative regions where "low-low" clusters were discovered; all other regions failed the significance test ($p<0.05$). (Fig. 4c).

From 2010 to 2019, grain yield in Xinjiang was concentrated at a "low-low" level. While Shandong and Anhui both display a 'high-high' concentration of grain yield in 2010–2019, Sichuan has a 'high-low' concentration. The rest of the provincial administrative regions failed the significance test in 2010-2019 (p 0.05), however Jilin demonstrated a "high-high" concentration in 2015-2019 and did not pass the test in 2010. (Fig. 5). The three provincial-level administrative

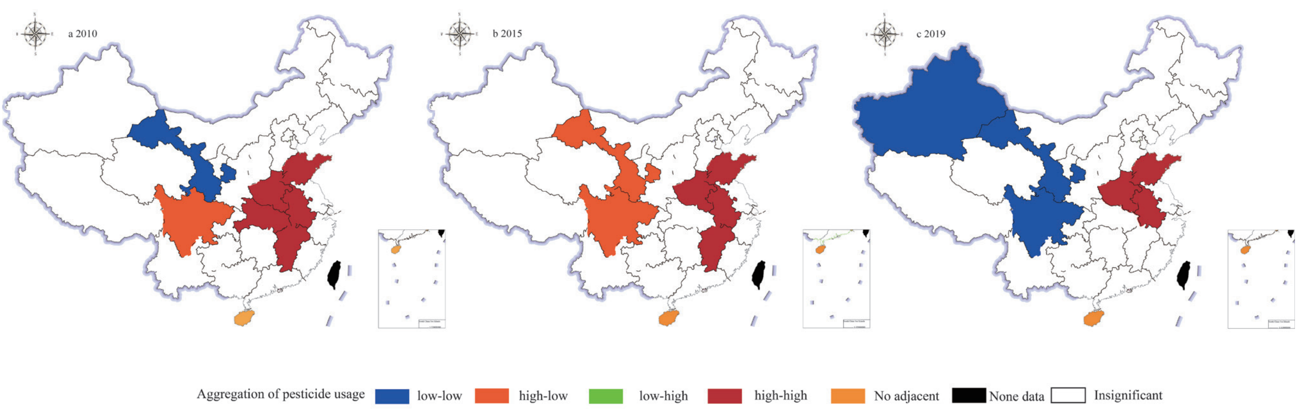

Fig. 4. Local spatial autocorrelation LISA clustering of pesticide usage from 2010 to 2019.

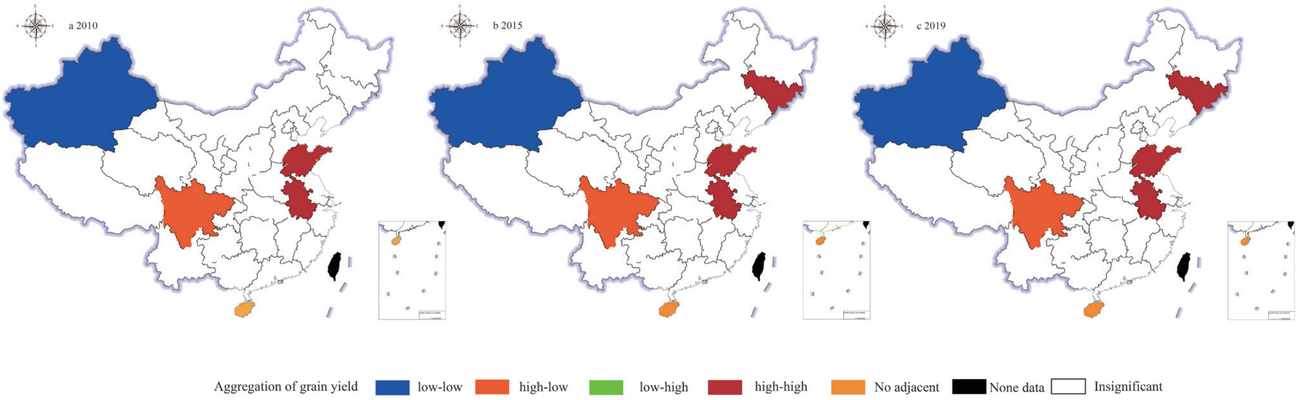

Fig. 5. Local spatial autocorrelation LISA clustering of grain yield from 2010 to 2019.

regions of Shandong, Henan, and Anhui are therefore the "high-high" concentration areas for pesticide usage in 2010-2019, and Shandong and Anhui are the "high-high" concentration areas for grain yield in 2010-2019.The aforementioned provincial governments are situated in China's North China Plain. The area is one of China's major grain-growing and production regions, and due to the region's large population and extensive grain-growing, pesticide usage is also substantial. Some provincial administrative regions have reduced the use of pesticides to some extent since the "double reduction" policy was introduced in 2015.Sichuan, Jiangxi, Anhui, and other provinces have gradually stopped using pesticides in areas with "high - low" concentrations and "high - high" concentrations. In terms of scale or average amount, pesticide usage is high in these provincial-level administrative regions, and pesticide reduction needs to be further promoted. Shandong, Anhui, and other provincial-level administrative regions are still in the "high-high" concentration areas of pesticide usage and food production.

The Dynamic Mechanism that Links Grain Yield and Pesticide Application

A total of 16 provincial administrative regions experienced rising pesticide usage between 2010 and 2014. In 15 of these provincial districts, an increase in grain yield – referred to as "double increase zones" – was also seen. Although the region's increased usage of pesticides has enhanced food output, it has also exacerbated ecological dangers. Pesticide usage is declining as food output is rising in 10 provincial administrations, a condition known as the "other-factor effect area". Food security and environmental safety have, to some extent, gone hand in hand as the region's food production has increased while steadily moving away from the effect of pesticide issues. Five provincial administrative regions, or "double reduction zones," demonstrated a concurrent decrease in pesticide usage and food output. The reduction in pesticide usage in the area helps to promote ecological security but not food security. In one provincial administrative region, the "excess zone" of Zhejiang Province, pesticide consumption increased but food output decreased. In addition to contributing to ecological deterioration, increased pesticide usage has a negative impact on food security. Prior to the implementation of the "double reduction" policy, the eastern and central areas were already in the "other-factor-influenced zone," where pesticide usage was decreased and food production grew. Food production and pesticide usage both "double up" in the western and northeastern regions. Overall, an isotropic connection has dominated the coupling properties of pesticide usage and grain yield in China during this time. The "double growth areas" in particular dominated the 63.33% of provincial districts that altered in the same way. It is obvious that the usage of pesticides at that time played a crucial part in ensuring our food security.

The "double reduction" policy was formally launched in 2015, and throughout the country, the relationship between pesticide usage and food production has changed dramatically at the provincial level. the creation of seven new "double reduction" districts and nine "other factor impact" districts from the previous 15 "double increase" provincial districts and one "excess" district. Additionally, the "double growth area" status of the Northeast and Western areas has changed to "other factor impact area." There are currently 12 "double reduction zones" that account for 38.71% of the total and 19 "other factor affected zones" that account for 61.29% of the total. Prior to the "double reduction," China had a "double increase zone" in terms of the overall type of coupling between pesticide usage and grain yield. Now, it has a "zone of other factors influence."

Regional Variations in the Amount of Pesticides Used in Crop Production

The region's arable land resources are changing rapidly as China's economy expands. Pesticide usage and food production in the area are both impacted by

Table 4. Coupling of pesticide usage and grain yield in China, 2010-2019.

Region	2010-2014		2015-2019		2010-2019	
	Elasticity factor	Coupling relationships	Elasticity factor	Coupling relationships	Elasticity factor	Coupling relationships
Eastern region	-2.55	Other factors affecting area	-0.17	Other factors affecting area	-0.42	Other factors affecting area
Beijing	2.03	Double reduction area	1.43	Double reduction area	1.30	Double reduction area
Tianjin	1.48	Double enrichment area	-0.64	Other factors affecting area	-1.29	Other factors affecting area
Hebei	28.25	Double enrichment area	-0.40	Other factors affecting area	-0.88	Other factors affecting area
Shanghai	0.16	Double reduction area	0.38	Double reduction area	0.33	Double reduction area
Jiangsu	-0.66	Other factors affecting area	-0.35	Other factors affecting area	-0.62	Other factors affecting area
Zhejiang	-0.37	Pesticide overdose area	0.44	Double reduction area	0.49	Double reduction area
Fujian	0.08	Double enrichment area	0.59	Double reduction area	0.70	Double reduction area
Shandong	-1.00	Other factors affecting area	-1.71	Other factors affecting area	-1.44	Other factors affecting area
Guangdong	0.40	Double enrichment area	0.24	Double reduction area	0.19	Double reduction area
Hainan	-0.17	Other factors affecting area	0.38	Double reduction area	0.30	Double reduction area
Central region	-7.05	Other factors affecting area	-0.42	Other factors affecting area	-1.04	Other factors affecting area
Anhui	-3.38	Other factors affecting area	-3.25	Other factors affecting area	-2.91	Other factors affecting area
Shanxi	1.15	Double enrichment area	-0.40	Other factors affecting area	-7.44	Other factors affecting area
Jiangxi	-0.79	Other factors affecting area	-0.01	Other factors affecting area	-0.25	Other factors affecting area
Henan	1.03	Double enrichment area	-0.87	Other factors affecting area	-2.92	Other factors affecting area
Hubei	-1.38	Other factors affecting area	-0.05	Other factors affecting area	-0.68	Other factors affecting area
Hunan	1.40	Double enrichment area	0.05	Double reduction area	-0.29	Other factors affecting area
Northeast region	2.69	Double enrichment area	-1.73	Other factors affecting area	-11.09	Other factors affecting area
Liaoning	0.04	Double reduction area	-2.96	Other factors affecting area	-1.55	Other factors affecting area
Jilin	0.64	Double enrichment area	-0.43	Other factors affecting area	1.59	Double enrichment area
Heilongjiang	2.16	Double enrichment area	-3.58	Other factors affecting area	-34.31	Other factors affecting area
Western region	0.60	Double enrichment area	-0.10	Other factors affecting area	-1.35	Other factors affecting area
Neimenggu	1.44	Double enrichment area	-4.50	Other factors affecting area	4.44	Double enrichment area
Guangxi	0.68	Double enrichment area	0.74	Double reduction area	0.85	Double reduction area

Table 4. Continued.

Chongqing	0.06	Double reduction area	0.35	Double reduction area	0.20	Double reduction area
Sichuan	-0.82	Other factors affecting area	-0.06	Other factors affecting area	-0.28	Other factors affecting area
Guizhou	-0.50	Other factors affecting area	0.27	Double reduction area	0.13	Double reduction area
Yunnan	1.11	Double enrichment area	0.01	Double reduction area	-2.25	Other factors affecting area
Xizang	-63.32	Other factors affecting area	-0.09	Other factors affecting area	-0.47	Other factors affecting area
Shanxi	0.56	Double enrichment area	-0.03	Other factors affecting area	-1.34	Other factors affecting area
Gansu	0.28	Double enrichment area	0.01	Double reduction area	-1.35	Other factors affecting area
Qinghai	-0.23	Other factors affecting area	-0.10	Other factors affecting area	-0.10	Other factors affecting area
Ningxia	-2.72	Other factors affecting area	-0.01	Other factors affecting area	-0.16	Other factors affecting area
Xinjiang	0.23	Double enrichment area	-0.02	Other factors affecting area	0.44	Double enrichment area
China	3.88	Double enrichment area	-0.33	Other factors affecting area	-1.14	Other factors affecting area

changes in arable land. Because of this, the quantity of pesticides used per unit of food cultivation area (also known as the "pesticide usage intensity") can more properly reflect how different regions are implementing pesticide application reduction programs. Except for Beijing, every single one of the 30 administrative regions at the provincial level exhibited a drop in the frequency of pesticide usage between 2015 and 2019 (Table 5). The intensity of pesticide usage in the eastern, central, and northeastern areas exhibited a general decline between 2010 and 2014, with a minor comeback in intensity during that time, when viewed from the perspective of the four primary regions. While there was an increase trend in the western region. In comparison to the nation as a whole, all four regions exhibit a declining trend in pesticide usage intensity from 2015 to 2019. where the North East saw an increase in the intensity of pesticide usage in 2017 compared to 2016 before continuing to decline year over year. Together, the strategies for reducing the use of pesticides in all regions have been better carried out until 2019.

Paying close attention to the connection between pesticide usage and food production is a crucial feature of China's agricultural production in order to guarantee both national food security and ecological safety [18-22]. However, the reduction of pesticides and increasing food production are incompatible [23-28]. Thus, in the „double growth zones," the plan for zero growth in pesticide usage should be kept in place. In accordance with local conditions, farmers should be actively encouraged to utilize physical, biological, and agricultural techniques to manage pests, diseases, and weeds in their fields. In the end, this lessens the harm that pesticide usage does to the environment. Research should be done to determine the precise causes of the decline in local food production in „double reduction zones." To boost food production based on lower pesticide usage, efficient production technology systems should be brought to the region. Experience with the use of sophisticated pesticides and other production methods in the region should be compiled for „other affected areas." Additionally, these insights will be shared with other areas. This will make it possible for other places to alter the way they see farming in light of regional conditions and reduce the usage of pesticides while maintaining food security. Different geographical areas rely on pesticides to varying degrees for producing food. In the process of agricultural extension, regional peculiarities should be recognized.

The overall amount of pesticides used in China increased consistently from 2010 to 2014. It has increased food production significantly, but it has also increased pressure on ecological security. The usage of pesticides during this time has already been controlled by several provincial governments. An rise in grain yield and a decrease in pesticide usage have been accomplished in Jiangsu, a significant grain-producing province. All areas of the nation have seen a significant decrease in pesticide usage since the „double reduction" policy was put into place in 2015. Overall pesticide usage has decreased and food production has increased in all four of the regions. Despite using less pesticides, some provincial regions have not been able to boost food output. The area

Table 5. Intensity of pesticide usage in food production by region in China, 2010-2019.

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Eastern region	21.61	21.95	21.30	21.86	21.50	21.52	20.85	20.26	17.76	16.86
Beijing	12.75	13.06	14.03	16.44	18.50	18.59	20.61	22.33	25.05	25.97
Tianjin	8.43	8.59	8.46	8.16	8.13	8.08	7.44	5.46	5.12	5.36
Hebei	10.24	10.03	10.14	10.30	10.21	9.85	9.65	9.26	7.50	7.05
Shanghai	16.84	15.00	14.44	12.78	12.71	12.55	12.84	12.28	11.34	10.71
Jiangsu	12.07	11.52	11.06	10.69	10.44	10.15	9.97	9.69	9.26	9.06
Zhejiang	28.03	28.18	30.01	30.16	29.55	28.57	25.43	23.37	22.09	19.30
Fujian	29.91	31.03	32.82	33.20	33.77	34.50	35.77	33.69	31.13	28.45
Shandong	15.44	15.28	14.91	14.22	13.82	13.27	13.18	12.67	11.73	11.00
Guangdong	24.49	26.88	26.81	26.35	26.67	27.13	27.19	26.73	21.90	20.08
Hainan	57.83	59.94	50.35	56.31	51.19	52.54	46.45	47.08	32.54	31.65
Central region	13.56	13.42	13.40	13.14	12.83	12.51	12.40	11.82	11.14	10.21
Anhui	12.42	12.51	12.50	12.58	12.00	11.56	12.02	11.39	10.74	10.05
Shanxi	7.17	7.69	8.06	8.32	8.46	8.58	8.52	8.05	7.45	7.18
Jiangxi	19.35	17.94	17.94	17.72	16.73	16.51	16.26	15.55	13.89	11.36
Henan	8.72	8.95	8.92	8.92	8.82	8.65	8.53	8.19	7.68	7.29
Hubei	18.98	18.71	18.15	16.45	16.18	15.12	14.84	13.78	12.99	12.41
Hunan	14.74	14.72	14.82	14.88	14.80	14.65	14.23	13.94	14.08	12.99
Northeast region	10.41	9.48	9.88	10.15	10.14	9.93	9.49	9.56	8.85	8.14
Liaoning	17.57	14.16	14.43	14.44	14.29	13.82	13.27	13.78	13.10	12.12
Jilin	8.14	8.61	9.43	10.10	10.10	10.39	9.65	9.25	8.39	7.96
Heilongjiang	5.53	5.67	5.78	5.91	6.03	5.60	5.56	5.63	5.06	4.35
Western region	5.57	6.10	6.25	6.37	6.56	6.66	6.58	6.02	5.44	4.95
Neimenggu	3.30	3.25	3.90	4.00	3.82	3.92	3.61	3.95	3.35	3.07
Guangxi	10.94	11.22	11.23	11.36	12.30	12.32	14.36	12.14	11.67	11.37
Chongqing	6.68	6.29	5.87	5.54	5.60	5.50	5.28	5.24	5.14	4.93
Sichuan	6.79	6.72	6.47	6.40	6.33	6.23	6.11	5.83	5.34	4.78
Guizhou	2.63	2.90	2.79	2.51	2.43	2.48	2.44	2.37	2.03	1.68
Yunnan	7.38	7.43	8.29	8.00	8.36	8.59	8.63	8.50	7.63	6.83
Xizang	4.57	4.57	4.09	4.43	4.40	4.79	4.18	4.33	3.70	2.95
Shanxi	2.93	2.96	3.11	3.16	3.16	3.23	3.17	3.27	3.08	2.95
Gansu	11.98	18.12	19.55	20.58	20.60	20.91	18.64	13.86	11.37	10.94
Qinghai	3.99	3.70	3.25	3.60	3.43	3.58	3.41	3.42	3.23	2.53
Ningxia	2.16	2.24	2.30	2.35	2.31	2.30	2.32	2.21	1.97	1.91
Xinjiang	3.52	3.80	4.17	4.56	5.99	6.09	6.84	7.13	6.80	5.48
China	11.02	11.10	11.14	11.05	10.96	10.75	10.55	10.07	9.21	8.49

of crops grown in the area is mostly relevant to this. For instance, since 2016, the area planted with grains in Guizhou and Hunan has clearly been trending downward, which has also lowered grain yield. In order to achieve this, this report offers a statistical analysis of the level of pesticide usage by nation-wide region from

2010 to 2019. From a national standpoint, the pesticide application reduction initiative has been successfully carried out across the nation. In addition to ensuring the general rise in food production, efforts have been made to mitigate some of the ecological stress.

Conclusions

The usage of pesticides has been firmly under control because to China's double reduction program. But it has also limited how much grain yields have increased, particularly in western areas like Xinjiang. In China's major grain-producing provinces like Shandong and Anhui, pesticide usage is still significant. When seen together, China has experienced better progress on implementing its pesticide application reduction plan through 2019.

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Conflict of Interest

The authors declare no conflict of interest.

Supporting Information

Supporting Information available at http://www.pjoes.com/SuppFile/157550/7658/0a698b3581f97376431cca357bf3b3f2/

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