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EFFECT OF ENVIRONMENT AND INVESTMENT ON WINTER WHEAT PRODUCTION ON THE LOESS PLATEAU OF CHINA

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Abstract

Human investment and environmental changes exhibit great impacts on winter wheat production. In present paper winter wheat yield adjusted into environment yield and investment yield, to evaluate the effects of environment and investment on winter wheat production on the Loess Plateau of China. The results showed the mean value of environment yield at period IV was 851 kg/hm^2, with the RE value of 25.6% and during the last 57 years the impacts of environment change on winter wheat yield were negligible. However, the climate changes, particularly fluctuations in the precipitation cycle caused the variation in winter wheat yield/year. In addition the investment yield of winter wheat at period IV was 2663 kg/hm^2, with the RI value of 74.4%. Therefore, it is inferred that investment was one of the main reasons which increased winter wheat yield from 1965 to 2014 on the Loess Plateau of China; while RI values were lower during prolonged drought seasons. Consequently we conclude that the impacts of investment on winter wheat yield were limited by the environmental factors especially by rainfall on the Loess Plateau of China.

Key words: *Wheat; Climate change; crop yield; human investment; rain fed areas.*

INTRODUCTION

The Loess Plateau of China is one of the typical rain-fed areas in the world, and winter wheat is one of the main staple crops which grown in this area for centuries (Li and Mingbin, 2008). The Loess Plateau is facing severe problems relevant with climatic changes particularly due to anthropogenic interference which are extensively involved in agrarian practices during last fifty years. Most researchers believed that climate changes decreased winter wheat yield (Ortiz, et al., 2008). However, during 2000-2014, winter wheat yield (3171kg/hm2) which was nearly 3.6 times higher than the production recorded during 1958-1980. Therefore, it is important to understand the winter wheat yield trends in relation with environmental regimes during last 50 year on the Loess Plateau. During last 50 years, temperature exhibited an ascending trend and changed at a rate of 0.04℃/a on the Loess Plateau (Yao et al., 2011). This increased trend in temperature magnified the hazardous effects on winter wheat particularly an increase of 10-20% diseases caused by powdery mildew during onset of the spring (Xiao, 2010). Most scientists believed that increased trend of temperature have negative impacts on winter wheat yield. However, temperature rising also caused decreasing of temperature stress on winter wheat during winter and spring seasons (Wang, et al., 2008; Yao et al., 2011), reported that temperature increasing has a positive impact on winter wheat during sowing-seeding and maturity stages. Moreover, some researchers also pointed out that winter wheat yield were not linearity related with temperature and precipitation (Shang, 2009).
Compared with temperature, precipitation displayed a descending trend with the velocity of -1.6 mm/a, during the last 50 years on the Loess Plateau (Yan-Qing et al., 2011). This climate change caused a marked ascending trend of aridity index and caused the winter wheat yield reduced significantly in the northern regions of the Loess Plateau (Zhan-Sheng et al., 2008). Winter wheat yield is very sensitive to precipitation during the jointing and earring stages (Hiltbrunner, J et al., 2007; Dickin and David, 2008). Therefore, precipitation decreasing, at these two stages, caused a reduction in winter wheat yield (Yao et al., 2011). However, some research reported that climate change on the Loess Plateau would have positive impacts on winter wheat production (Wang,

2008). Global warming, as a result of climate change, may also be negatively affect winter wheat yields, however, current effects of climate change in relation to winter wheat are inconclusive and model dependent (Boykoff, Maxwell et al., 2010; Wang et al., 2011). Human investment has a positive impact on agriculture production and increases winter wheat yield in the world (Reynolds and Borlaug, 2006), believed that massive applications of machine, fertilizer, irrigation and labor were the main reasons causing winter wheat yield increase in China. Statistical data showed that the development of agriculture science and technology increased winter wheat yield dramatically on the Loess Plateau of China during last 50 years.

Little human investment was used for winter wheat before 1970, few chemical fertilizers and machineries or new technologies were applied for winter wheat, and yield of winter wheat mostly depended on local environmental conditions. During 1958 to 1970 the average yield of winter wheat was 887 kg/hm^2; however it reached to 3171 kg/hm^2 during 2000 to 2014 (Gao et al., 2017). Econometric model showed that machinery energy was one of the major contributors which affect the output level of winter wheat cropping system (Mobtaker et al., 2010). During growing periods of 2010-2014 application of fertilizer for winter wheat were also increased from 282 to 330 kg/hm^2 (near to 10 times more than it was in 1957-1980) and was one of the key factor to increase winter wheat yield in China (You-Liang et al., 2007; Simelton et al., 2008). Moreover, some new technologies, especially saving water techniques, make the yield of winter wheat increased dramatically on the Loess Plateau of China (Zhang, et al., 2017). Most of the research indicated that human investment has positive impacts on agriculture production; however, how and how much these impacts exhort there effects on winter wheat production is not clear on the Loess Plateau of China. Therefore the objectives of present study were: 1) to investigate the impacts of environment and investment on winter wheat production by using real time weather data and winter wheat yield for a specific period. 2) To point out some advices to the farmers and scientists for winter wheat production on the Loess Plateau and related areas in the World.

MATERIAL AN METHODS

Experiment site: Changwu (35°12'N, 107°80'E) located at the hilly region of the Loess Plateau of China. It has 233 villages with the population of 17.3×104 (15.9×104 of them work as farmers) and the arable land of 2.53×104 hm2. It’s a semi-humid and warm climatic zone inundated during continental monsoon period with the average annual rainfall of 580 mm (average annual temperature of 9.1℃ and annual radiation of 4837 J/cm2). There was no source of surface irrigation for the crops, and all agricultural production depended upon the rainfall. Therefore, characteristically it is a rain-fed agricultural region. Winter wheat, as the primary crop in this region, was planted during at late September and was harvested at the beginning of June

Data sources: The data of average annual yield for winter wheat during 1958-2014 was collected from Agro-technology Center of Changwu, China. The Meteorological data from 1958 to 2014 collected from Changwu Meteorology station. The field experiments for fertilizer doses were carried out at Agro-technology Center of Changwu during 1965-2014.

METHODS TO ANALYSIS

Categorization of rainfall/annum: In the hilly and gully regions (Changwu for example) on the Loess Plateau, fallow period of winter wheat started from July to September and growth period was from early October to early June. Therefore, production cycle of winter wheat was from July to June on the Loess Plateau (figure 1). (Figure. 1) Production cycle of winter wheat on the Loess Plateau of China

July.	Aug.	Sept.	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Fallow period			Production period								
Production cycle											

Based on the annual rainfall and their mean value from 1965 to 2014, we classified all the production years into five classes using equation 1 and a decision table (Table 1). Where PAP was Precipitation Abnormity Percentage, R was the total precipitation from July to June. R0 was the mean value of precipitation from 1965 to 2014.

$$\mathrm{PAP} = \frac{\mathrm{R} - \mathrm{R_0}}{\mathrm{R_0}} \times 100\% \quad (1)$$

Table 1. Decision table to divide the rainfall years from 1968 to 2014 at Changwu

Rainfall pattern of different production year	Value of PAP
Extra arid production year	PAP≤-30%
Arid production year	-30%＜PAP≤-10%
Normal production year	-10%＜PAP≤10%

Continued table 1

Rainy production year	10%＜PAP≤30%
Extra rainy production year	30%＜PAP
Extra arid production year	PAP≤-30%

Dividing of winter wheat production period: Period I, low yield period (figure. 2), was an extensive sowing period but meager harvest period with the duration of 13 years from 1958 to 1970. During this period, most varieties of winter wheat were introduced from other places. Winter wheat was cultivated in the legume-winter wheat rotation cropping system. No chemical fertilizer was used for winter wheat and most organic manure was used for economic crops. Livestock was the primary power used for plough; no machine was used for winter wheat. The yield of winter wheat, during this period, was not higher than 1500 kg/hm^2, with the mean value of 867 kg/hm^2.

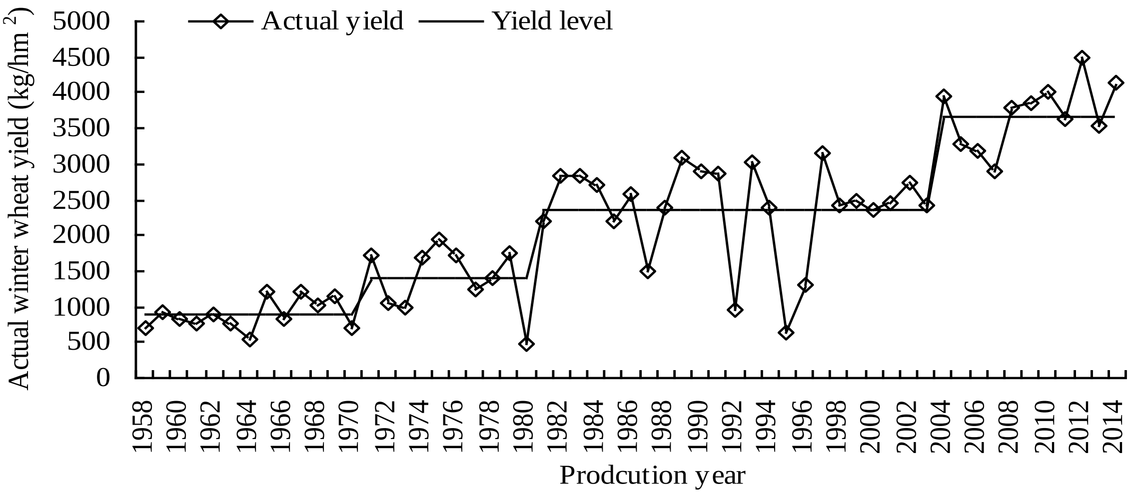


Figure. 2. Winter wheat yield and its production period at Changwu

Period II, yield increasing period was a period when winter wheat yielded increasingly a little from 1971 to 1980. During this period, the government of China started to encourage scientists to breed new variety of winter wheat; it urged farmers to use chemical fertilizer and machinery for winter wheat. So, the yield of winter wheat in this period started to increase and was higher than 1500 kg/hm^2 with the mean value of 1401 kg/hm^2.

Period III, medium yield period (figure 2), was a medium and relative stable yield period from 1981 to 2003. During this period the Household Contract Responsibility system was implemented by the government of china, mobilized the enthusiasm of farmers to produce more agriculture production, strengthened material and technological investment for agriculture. Some new varieties of winter wheat (Changwu 131 and Changwu 134 for example) and new technology (Micro-water harvesting, film mulching and straw mulching for example) were the major scientific breakthrough for winter wheat during this period. Therefore, winter wheat yield during this period increased dramatically with the mean value of 2340 kg/hm^2, and with the highest value of 3158 kg/hm^2, the lowest value of 649 kg/hm^2. Period IV was recognized as high winter wheat yield period (figure 2) from 2003 to 2014. Fertilizer investment was increased and was optimized during this period; the ability of winter wheat to resist environmental stresses and diseases was enhanced during this period. Therefore, its mean annual yield reached to 3615 kg/hm^2, with the highest value of 4500 kg/hm2 and the lowest value of 2415 kg/hm^2.

Quotient of winter wheat yield: Environment factors and human factors were two important factors to affect crop yield. So crop yield can be divided into environment yield and investment yield (equation 2). In this research, environmental included rainfall and temperature. Human factors referred to the anthropogenic intervention on agriculture such as fertilization, irrigation, cultivation and breeding.

YF = YE+YI （2）

Where YF was actual winter wheat yield, YE was the winter wheat yield by environment; YI was the winter wheat yield by investment. The value of YI during 1958 to 1970 was near to 0 (YF≈YE), based on the following derivatives. 1) Varieties of winter wheat were alien crops in this region. 2) No use of chemical fertilizer and machinery for winter wheat. 3) The impacts of investment on winter wheat yield were modicum. Hence afterward, YF equal to YE (YF≈YE) at period I. For other production periods, we can use equation 3 to calculate the mean value of YI.

YIi = YFi-YE0 （3）

Where YIi was the investment yield at period i; YFi was the mean actual yield of winter wheat at period i. YE0 was the environment yield at period I_0. Once we got the value of YI for different production periods, we can use these values in equation 4 and 5 to calculate the value of YE for subsequent years.

YEij = YFij-YIi i≥II（4）

YEij = YFij i=I（5）

YEij was the environmental yield in the year j during period i; YFij was the actual winter wheat yield in the production year j during period i; YIi was the investment yield at period i.

In order to evaluate the difference of YI in precipitation/year and production periods, we estimate equation 6 and equation 7.

YImi=YFmi-YEm i≥II（6）

YImi=0 i=I（7）

Where YImi was the value of YI in the year of m in period i. YFmi was the value of YF in the year of m at period i. YEm was the value of YE in the year of m during period i.

Contribution rate of investment and environment on winter wheat yield was calculated by using equation 8 and 9 respectively

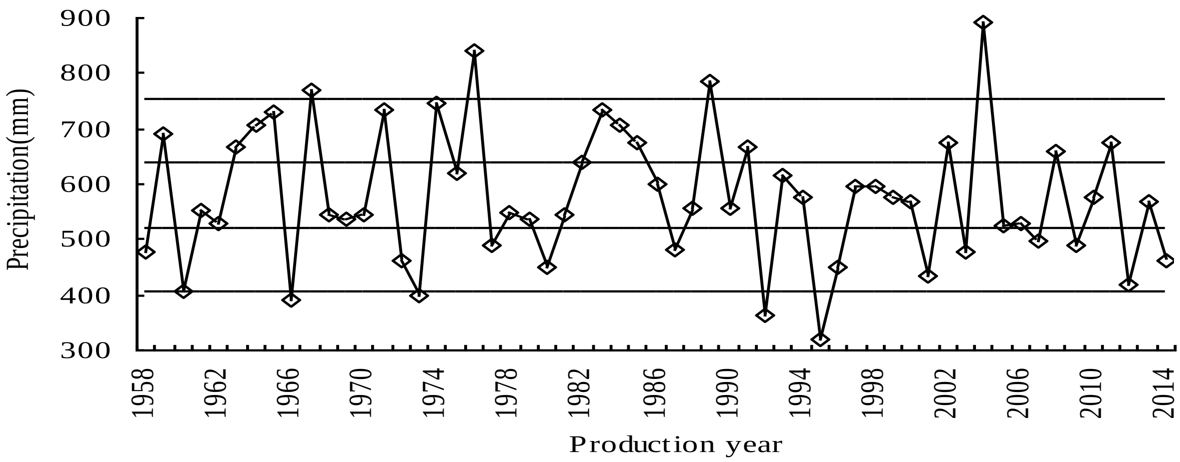
RI= YImi /YFmi×100% (8)

RE=YEmi/YFmi×100% (9)

Where RI and RE were relative contribution rate of investment and environment on winter wheat yield and YImi and YEmi was the value of YI and YE in the year of m at period i respectively. Moreover, YFmi was the value of YF in the year of m at period i.

RESULTS

Rainfall at Changwu from 1958 to 2014: From 1958 to 2014, mean annual rainfall at Changwu was 580 mm, with the highest value of 890 mm reported during 2004 and the lowest value of 293 mm during year 1995. Among 57 production years in question, 5 years were categorized extra arid, 12 years were arid, 23 years were normal, 13 years were rainy and 4 years were extra rainy year (Figure 3). The probability values between extra rainy year and extra arid year were 7.02% and 8.77% respectively. Similarly the probability values for arid, normal and rainy year were 21.05%, 40.35% and 22.8% respectively.



(Figure. 3) Rainfall and its distribution in different years at Changwu, **A** was extra arid years; **B** was arid years; **C** was normal years; **D** was rainy years; **E** was extra rainy years

Mean value of precipitation in the subsequent period, from July to September, was 310 mm (58.5% of the total annual rainfall). Only 41.5% of the rainfall took place during the growing season from October to June. The total precipitation during winter season from October to April was 106 mm which comprised only 20% of total rainfall/year and considered drought season at Changwu. Based on statistical data it is apparent that drought season at Changwu County prevailed during winter to spring seasons (56.8%).

Winter wheat yield produced by environment: Mean value of YE environmental yield at periods I, II, III and IV were 867, 856, 852 and 851 kg/hm2 respectively in table.2. The environmental yield showed no significant differences among different production period, however, precipitation/year had shown significant impacts on environmental yield of winter wheat (Figure 4). The environmental yield correlated significantly with the precipitation in fallow periods and in production years, with the correlation coefficient of 0.81 and 0.37 respectively. However, the correlation between environmental yield and precipitation during growing period was not significant.

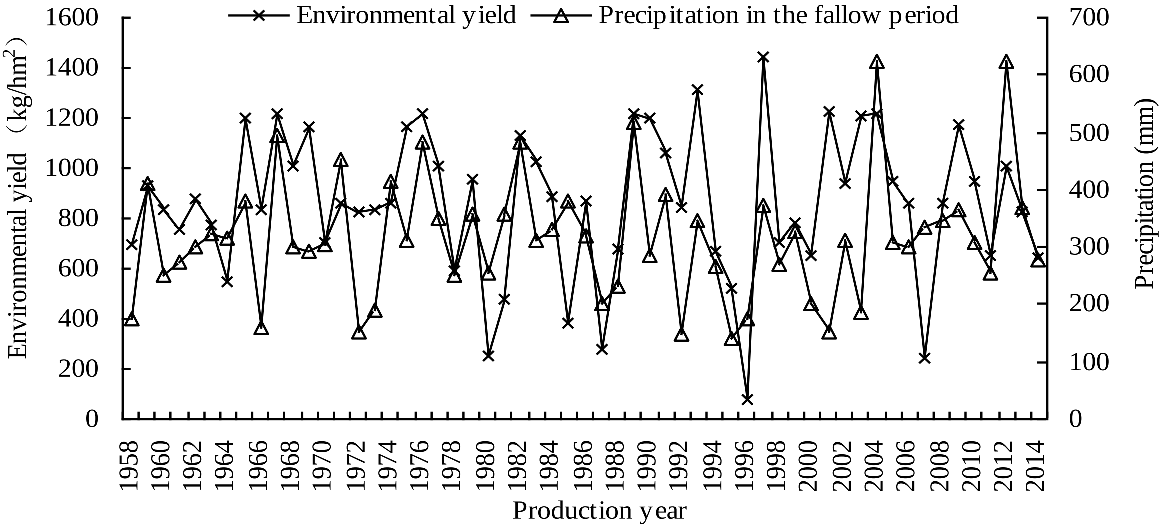


Figure. 4 Annual precipitation in fallow period and the winter wheat yield produced by environment from 1985 to 2014 at Changwu

Moreover, the mean values of environmental yield during in extra drought years and extra rainy years were 773 and 1218 kg/hm2 compared with drought years, normal years and rainy years which were 696, 900 and 854 kg/hm^2 respectively.

Table.2 Comparison of winter wheat yield produced by environment in different rainfall years and different production periods at Changwu (kg/hm^2)

Production period	Extra drought years	Drought year	Normal year	Rainy year	Extra rainy year
I	833	697	901	859	1218
II	802	682	895	850	1219
III	682	700	903	844	1216
IV	(NA*)	705	901	862	1219

* = Data not available

The environmental yield correlated significantly with the precipitation in fallow periods and in production years, with the correlation coefficient of 0.81 and 0.37 respectively. However, the correlation between environmental yield and precipitation during growing period was not significant.
The relative impacts of environmental factors on winter wheat yield were reduced from years 1965 to 2014. The RE values at production period were 76.8, 53.8, 36.9, and 25.6% for production periods I, II, III and IV, respectively.

Impacts of investment on winter wheat yield: The impacts of investment on the winter wheat yield can be accumulated during the cultivation of winter wheat for a longer period. Therefore, the relative investment yield of winter wheat and contribution rate of investment on winter wheat both were increased with the elevating of production period. The higher investment value of 2663 kg/hm2 recorded during the period IV, compared with period II which showed the lowest value of 495 kg/hm2. The value of Relative contribution rate of Investment yield to actual yield (RI) was higher (74.4%) during period IV compared with period II (33.2%).
The impacts of investment on winter wheat yield were influenced by the environmental factors, predominantly by the precipitation pattern, which exhibited fluctuations in percentage of rainfall, during a prolonged period which comprises of years 1958-2014. The investment yields of winter wheat in rainy and extra rainy years were higher compared with drought and extra drought years. However the value of RI in drought, normal and rainy years were significantly higher compared with extra drought and extra rainy years (table 3).
The results of present study indicated that the impact of investment on winter wheat yield was diminutive during years with extreme weather patterns in precipitation percentage that included extra drought years or extra rainy years on the Loess Plateau.

Table.3 Investment yield and its relative contribution rate for winter wheat yield in different rainfall years and different production periods

Production period	*Extra drought years*		*Drought years*		*Normal years*		*Rainy years*		*Extra rainy years*	
	Yield kg/hm²	RI %	Yield kg/hm²	RI %	Yield kg/hm²	RI %	Yield kg/hm²	RI %	Yield kg/hm²	RI %
I	0	0	0	0	0	0	0	0	0	0
II	157	15.9	232	25	795	46.8	846	49.5	495	28.9
III	127	13.3	1219	63.6	1707	65.4	1805	77.7	1860	60.5
IV	—	—	2678	79.3	2323	72.0	2919	77.2	2730	69.2

DISCUSSIONS

Climate and winter wheat production: Results of present study showed the environmental yield of winter wheat slightly decreased from periods I to IV, however, these differences in yield were not significant. Current study provide a strong evidence that climate change caused the winter wheat yield reduced but not significant, that are different with the result of some researchers who showed a significantly negative or positive impacts of climate change on winter wheat production on the Loess Plateau of China (Li, C et al., 2017). It is true that rainwater harvesting technologies can help farmers to collect and use rainwater effectively for the production of winter wheat in arid regions of world (Atreya, et al., 2008; Yang et al., 2011; Wang et al., 2008). However great water stress, caused by the great shortness of water, limited the growth of winter wheat during extra drought years. Investment for agriculture, such as water harvest and fertilizer, did not contribute in enhancing the final yield of winter wheat, particularly during extra drought years (Table. 3). During extra rainy years, the rainfall was relatively sufficient than the need of winter wheat and the impact of various agricultural technologies, particularly those implement for saving rainfall exhibited little impacts on winter wheat yield. Hence, the value of RI during extra rainy years was lower comparing with rainy, normal and drought years (Table. 3). The results of present study showed that the environmental yield was significantly correlated with the precipitation in fallow period and production year (Figure. 3). However, most of researchers viewed that the rainfall was decreased during both the fallow and the growing seasons of winter wheat on the Loess Plateau of China (Wang T et al., 2011; Wang, Xue et al., 2011). Due to this descending trend in precipitation, the environmental yield of winter wheat decreased on the Loess Plateau of China. However these impacts on winter wheat production were negligible, because the contribution rate of environment (26%) was significantly lower than that of investment (74%). Results based on simulation model showed that the fluctuations in precipitation and temperature during different years were the consequences of global warming (Poortinga, 2011; Pidgeon and Catherine, 2009). The results of present study indicated that fluctuations in precipitation of different production years were the main reasons in disparity of environment yield of winter wheat on the Loess Plateau. Therefore, there is a possibility of discrepancy in winter wheat yields in coming years due to rapid vacillation in environmental factors.

Investment and winter wheat yield: Results of study carried out by (Zhang et al., 2017) showed that dry soil layers in deep soil affected the winter wheat yield in subsequent years on the Loess Plateau of China. However, results of present study showed that discrepancy in precipitation within a year also showed impacts on winter wheat yield. Moreover, it is clear from results of present study that unreasonable investment for enhancing winter wheat yield escalating fluctuations during production periods III and IV. Therefore, it is concluded that dry soil layer and unreasonable investment on winter wheat were one of the main causes of the fluctuation of winter wheat yield during subsequent years. Hence, based on these findings, we suggest that the reasonable investment can decrease the fluctuation of winter wheat on the Loess Plateau.

The relative contribution rate of investment on winter wheat yield (RI) was inversely proportioned when compared with the relative contribution rate of environment on winter wheat yields (RE) from production periods of I to IV. From these results it is, therefore, suggested that it was the strengthening of investment that actually increased the winter wheat yield on the Loess Plateau during last fifty or more years. Therefore, it is recapitulated that the best way to tackle the impacts of climate change on winter wheat production was to invest reasonably and effectively.

Data obtained from the experimental fields at Changwu Agro-technology Center showed that increase rate of winter wheat yield by same nitrogen fertilizer was reduced to 6.6% in 2014 from 49.2% in 1965. Similarly increased rate of winter wheat yield by same phosphorus reduced to 21.5% in 2014 from 91.2% in 1965. Moreover, potassium content in the soil was 142 mg/kg in 2014 which reduced 26mg/kg comparing with it in 1983. From these findings it is suggested that in the future, the application of N, P and K composition should be more reasonable for obtaining maximum yield of winter wheat on the Loess Plateau of China.

CONCLUSIONS

1) Mean value of environment yield at period I, II, III and IV were 867, 856, 852 and 851 kg/hm2 with the relative contribution of 76.8%, 53.8%, 36.9%, and 25.6% on winter wheat production. During the last 57 years the impacts of environmental changes on winter wheat yield were insignificant. While the climate changes, particularly fluctuations of precipitation in fallow seasons caused the oscillation in winter wheat yield production. 2) Investment yield of winter wheat at period IV was 2663 kg/hm^2, considerably higher than that of production period II of 495 kg/hm2. Investment was the main reasons caused winter wheat yield augmentation from 1965 to 2014. 3) While the impacts of investment on winter wheat yield were limited by the environmental factors particularly by precipitation on the Loess Plateau of China, the value of RI at extra drought years and extra rainy years were significantly lower than drought years, normal years and rainy years.

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Conflicts of Interest: The authors declare no conflict of interest.

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