Effects of Irrigation and Nitrogen on Maize Growth and Yield Components

Xiukang Wang and Yingying Xing

Abstract The purpose of this study was to investigate the effect of irrigation and nitrogen fertilization on maize growth and yield components. Three irrigation treatments were included, 100, 150, and 200 mm, and three nitrogen levels were applied as follows: high nitrogen was 240 kg ha^{-1}, medium nitrogen was 180 kg ha^{-1}, and low nitrogen was 120 kg ha^{-1}. The results indicated that the interaction of nitrogen and irrigation has no significant effects on maize height, but the signal factor has a significant effect on plant height in the whole growth period. The changing trend of crop growth rate in the whole growth period was increasing first and then falling, and the CK treatment was always lower than other treatments. The maize growth rate was related to the nitrogen fertilizer level, and the positive relationship between nitrogen fertilizer level and growth rate. In single factor of fertilization, there was a negative correlation between units increased in yield and unit nitrogen. The interaction of nitrogen and irrigation has significant effects on biomass yield. The greatest yield-increasing potential was obtained in MF treatment. At the same irrigation level, the grain yield increased and had a most significant correlation relation with the harvest index. The population physiological indices of maize were increased with irrigation amount and fertilizer level, except the harvest index, and the incentive of population physiological indices in irrigation was higher than nitrogen fertilization. Therefore, MFHW treatment may be considered the most efficient for maize production in the rain-fed area of the Loess Plateau, China.

Keywords Maize · Irrigation · Nitrogen fertilization · Harvest index · Grain yield

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1 Introduction

In the last several decades, the uses of irrigation and fertilization have led to the increases in crop production and food security (Godfray et al. 2010). Irrigation and fertilization are widely used for production of food crops such as maizeand wheat, mostly because it alters the farm environment by changing the soil water contents and soil nutrients which result in the increase of soil fertility and growth environment. Therefore, it would be necessary to improve the water use efficiency and fertilizer production efficiency in arid and semiarid regions, especially for field management purposes.

Nitrogen is an essential crop nutrient, which is consumed by the crop roots throughout the growing season. Most common forms of nitrogen found in the soils are organic N, ammonium, nitrate, and gaseous nitrogen. Nitrate leaching is the main loss of nitrogen fertilizer which will result in its accumulation in the deeper soil layers, and will make the groundwaterpolluted (Wang et al. 2015). Nitrate leaching potential depends on irrigation methods, soil properties, crops and crop rotation, management practices and climatic parameters. This necessitates the development of appropriate water and fertilizer application strategies so as to maximize their application efficiency and minimize fertilizer losses through leaching (Ajdary et al. 2007). The development of fertigation technology has provided a new technique for the high-efficient and high-yield crop production. In particular, fertigation technology has proven to be one of the most effective methods to increase water use efficiency (WUE), grain yieldand crop quality in dry farming agricultural areas (Singandhupe et al. 2003). Studies have indicated that fertigation technology is conducive to crop growth by decreasing the soil moist and reducing soil surface evaporation in dryland agriculture (Badr et al. 2010). Fertigation technology also has the benefit of improving the absorption of crops on soil nutrient, including protection of the stability of fertilizer on root zone. Studies have also demonstrated that the benefits of deficit drip irrigation of crops are the results of water saving 33%, improving irrigation WUE by 42%, and improving the maize yield and quality (Kaman et al. 2011). The absolute growth rate, spike weight, spike length, 100-grain weight, and yield were bigger in fertigation technology than furrow irrigation.

Previous studies have revealed that the maximizing total production of maize under irrigation and nitrogen management (Wang and Xing 2016). However, few investigations have investigated on how irrigation and nitrogen presently affects maize yield in Northwest China (Sun et al. 2011), particularly the modeling of water and nitrogen coupling were not taken into consideration. Moreover, the study on coupling effect of irrigation and fertilizer is an important part of the semiarid region. Until recently, there is also need for the coupling effect of irrigation and fertilizer on maize yield, and there are fewer results on effects of the interaction. In this paper, we would examine how irrigation and nitrogen fertilizationaffectsmaizegrowth, yield, and setup production models.

2 Materials and Methods

2.1 Experimental Sites

Field experiments were conducted in the Loess Plateau area at the Ansai Experimental Station (36° 52′N, 108° 10′E and altitude 1320 m) in Shanxi Province, Northwest China in 2014. The location has a semiarid and warm temperate climate with a mean annual temperature of 9.1 °C and an annual accumulated temperature (>0 °C) of 3150 °C. The mean annual precipitation is 580 mm, and annual pan evaporation-based potential evaporation is 1500 mm. The average annual sunshine duration is 2230 h, and there are over 171 frost-free days. The groundwatertable is approximately 50–80 m below the surface. The permanent wilting point was 22.3%. As shown in Fig. 1, the maximum temperature is very high, and the relative humidity is very low during the growing season.

2.2 Experimental Design

Maize (Zea mays, L. Liyu 18) seeds were sown on May 6 and harvested on September 21, 2014 (days of the year: 138). The experiment used randomly assigned field plots with three replicates per treatment in two years. There were three nitrogen fertilization and three irrigationtreatments. The three nitrogen (urea) fertilization was applied as follows: HN (240 kg/ha), MN (180 kg/ha), and ZN (120 kg/ha), and the three irrigation treatments were HW (200 mm), MW (150 mm), and LW (100 mm).

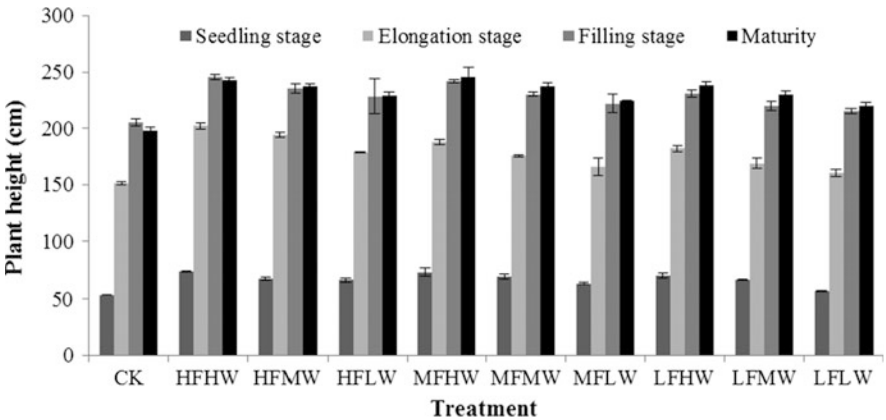

Fig. 1 Effects of different nitrogen and irrigation on plant height

Table 1 Different nitrogen and irrigation amount and time in maize growing season, the maize growing season was divided into four periods and the irrigation time in different periods according to the rainfall time

Fertilization	Irrigation	Seedling	Elongation	Filling	Maturing	Irrigation amount
CK		0	0	0	0	0
HF	HW	50	50	50	50	200
	MW	37.5	37.5	37.5	37.5	150
	LW	25	25	25	25	100
MF	HW	50	50	50	50	200
	MW	37.5	37.5	37.5	37.5	150
	LW	25	25	25	25	100
LF	HW	50	50	50	50	200
	MW	37.5	37.5	37.5	37.5	150
	LW	25	25	25	25	100

In this study, three check treatments were without irrigation, and the other treatments were examined as Table 1. Irrigation began when 60% of the surface field capacity (0–60 cm) was depleted by using the oven method, which generally occurred at the beginning of May in both years. The size of each experimental plot area was 10 m^2 (6 m × 3 m = 18 m^2). Planting density was 47,220 ha/plant. Each plot at planting time, spacing of 35 cm, 60 cm row spacing planting, planting depth of soil generally plummeted to the original seedling roots.

2.3 Measurements

Plant heights were determined by measuring the heights of two plants in one plot, which were measured from the ground level to the tips of the tassels at physiological maturity, from which the average plant height was determined. Crop growth rate is calculated as (CGR) = $(M2 - M1)/(T2 - T1)$, where CGR is crop growth rate; $T1$, $T2$ are days after sowing. $M1$ and $M2$ of $T1$ and $T2$, respectively, determine the amount of dry matter accumulation. In the harvest field experiments, the maize yield was calculated using the plot yield calculation method. The mature period randomly selected ten strains in every community, roots were dug up, the process was repeated three times; after aboveground harvest, straw, root, and grain were separated and air dried after weighing; the quality of dry matter, grain yield, and yield components were measured.Irrigationwater use efficiency (kg/m^3) was calculated by dividing the grain yield (kg/ha) by irrigation amount (m^3/ha). The irrigation water productivity was the ratio of the biological yield and irrigation water.

2.4 Statistical Analysis

An analysis of variance was conducted on the plant height, leaf area, root dry weight, shoot dry weight, and grain yield with SAS 9.2 (SAS Institute Ltd., North Carolina, USA). Duncan's multiple range tests were used for paired mean comparisons at a 0.05 probability level.

3 Results and Discussion

3.1 Plant Height

Plant height is an important index of maize growth, and the effects of different nitrogen and irrigation on plant height in whole growing season are shown in Fig. 1. In the whole growth period, plant growth was fast from seedling stage to elongation stage; in the filling stage, plant height growth slowed and mature plant height declined slightly. The CK treatment was significantly lower than other treatments, the interaction of nitrogen and irrigation has no significant effects on plant height, but the signal factor has a significant effect on plant height in the whole growth period. The plant height had a positive correlation with irrigation and fertilizer amount.

The highest plant height was 73.30 cm in HFHW treatment in seedling stages, and the average of plant height in HF was only 0.63 cm higher than MF treatment. However, the average of plant height in HW was 4.83 cm higher than MW treatment. The results might indicate that the plant height was sensitively in water than fertilizer. There was a significant difference between plant height in HF and LF treatment at the same irrigationlevel in elongation stage. The elongation stage is the fastest growth period of maize plant growth, and the average growth speed of plant height in HW, MW, and LW treatments were 4.94, 4.43, and 4.68 cm day^{-1}, respectively. There was no significant influence on plant height in irrigation and fertilizer treatment in filling stage, and the highest plant height was found in MFHW treatment, and the speed of plant growth was changed to slow. The average increase speed of plant height was 2.79, 3.44, and 3.23 cm day^{-1} in HF, MF and LF treatments, respectively. The results indicated that filling stage of plant growth rate is less than the rate of increase in elongation stage. In mature period, the plant height reduced except the HW treatment which may relate that the HW processing in the mature period of plant height has a certain role in promoting plant height increase. The research reported that maize height was not notable with the addition of nitrogen only improving its effect by about 3% (Midega et al. 2013). In most cases, the height of maize was not significantly different between the nitrogen levels and irrigation frequencies (Hokam et al. 2011).

Table 2 Models of different irrigation and fertilization on maize growth rate; y is the dry weight accumulation, x is days after sowing, and R^2 is the regression fitting the degree of relationship as the model

Treatments	Equation	R^2
CK	$y = -0.0063x^2 + 0.947x - 19.925$	0.8681
HFHW	$y = -0.0077x^2 + 1.37x - 30.466$	0.8873
HFMW	$y = -0.0089x^2 + 1.3723x - 29.485$	0.8644
HFLW	$y = -0.0103x^2 + 1.4195x - 29.651$	0.8461
MFHW	$y = -0.0073x^2 + 1.2718x - 27.796$	0.9141
MFMW	$y = -0.0073x^2 + 1.1758x - 25.161$	0.9074
MFLW	$y = -0.0095x^2 + 1.3396x - 28.093$	0.8410
LFHW	$y = -0.0082x^2 + 1.2729x - 27.25$	0.8755
LFMW	$y = -0.0092x^2 + 1.3434x - 28.588$	0.8260
LFLW	$y = -0.01x^2 + 1.3892x - 29.399$	0.7748

3.2 Crop Growth Rate

The field of maize growth rate with time change model under different irrigation and fertilization treatments as shown in Table 2, the relationship between maize-growth rate and growth time was consistent with polynomial relation and the better fitting coefficient of different treatments. The best fitting was MFHW treatment in this experimental, and the fitting coefficient was 0.9141, and the fitting coefficient was above 0.82 except LFLW treatment. The changing trend of crop growth rate in the whole growth period was increasing first and then falling, and the CK treatment was always lower than other treatments.

In seedling stage, the influence of different irrigationand fertilization on maize growth rate was not significant, and the growth rate was ranged from 1.293 to 1.534 g m^{-2} day^{-1} (Fig. 2). The growth rate of maize increased rapidly at elongation stage, and the growth rate was ranged from 8.538 to 13.008 g m^{-2} day^{-1}. The growth rate continued to increase in the filling stage, the HW, MW, and LW treatment of maize growth rate in high fertilizer levels were higher 75.76, 72.21 and 47.89% than CK, respectively. In the mature period, the growth rate was declined, but the rate of decline was negatively related to the fertilizer rate. The result indicated that the starting point of growth rate decline was related to the fertilizer rate, the higher of fertilizer amount, and the later decline point appeared of growth rate.

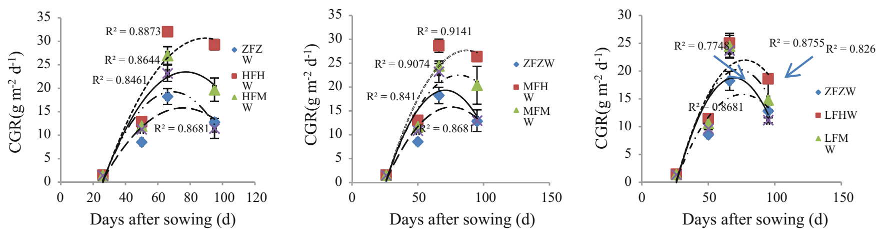

Fig. 2 The relationship between crop growth rate and days after sowing, CGR was crop growth rate

3.3 Yield and Its Components

The effect of different irrigation and fertilization on maize yield and its components are shown in Table 3. The spike length, spike weight, grain weight per spike, the 100-grain weight and yield increased with the increase of fertilizer application and irrigation amount, the nitrogen level very significantly affected the grain weight per spike and yield, and the irrigation level significantly affected the spike length and weight. The highest spike length was 17.34 in HFHW treatment which was 1.218 times higher than CK treatment, and the spike length was ranged from 14.24 to 17.34 cm in different irrigation and fertilization levels. Spike grain weight directly affects crop yields which were distributed in the range from 145.17 to 236.15 g plant^{-1}, and the highest spike weight was 236.15 g plant^{-1}, increased 62.7% than CK treatment. There was no significant difference between HW and MW treatment, but the HW and LW grain weight per spike significantly differed. HFMW, MFHW, and MFMW treatment than HFHW spike grain weight was reduced by 3.58, 1.37, and 5.20%, respectively, the results show that HFHW production efficiency was low. The 100-grain weight is another evaluation index of maize yield, which is the direct influence of the size and plumpness of maize seeds. The maximum of 100-grain weight was 33.9 g in HFHW treatment, which was significantly higher than the LFLW and CK treatment, but no significant difference with other treatment.

Table 3 Different irrigation and fertilization on maize yield and its components

Fertilization	Irrigation	Spike length (cm)	Spike weight (g plant^{-1})	Grain weight per spike (g plant^{-1})	100-grain weight (g)	Yield (kg ha^{-1})
CK		14.24c	145.17d	116.58d	25.84d	4599.09d
HF	HW	17.34a	236.15a	196.39a	33.90a	7923.02a
	MW	16.83ab	228.57a	189.36ab	32.32abc	7600.50ab
	LW	16.34b	207.68b	172.38bc	31.68abc	6918.94bc
MF	HW	17.21a	230.39a	193.70a	33.33ab	7774.90a
	MW	16.75ab	218.90ab	186.18ab	32.14abc	7473.06ab
	LW	16.30b	202.42bc	175.52bc	31.41bc	7044.98bc
LF	HW	16.31b	202.33bc	187.60ab	32.63abc	7529.85ab
	MW	16.09b	189.71c	164.20c	31.64abc	6590.60c
	LW	16.14b	185.50c	159.10c	30.63c	6386.10c
Nitrogen level		NS	NS	**	NS	**
Irrigation level		**	*	NS	NS	NS
Nitrogen × irrigation		NS	NS	*	NS	*

Values followed by the same uppercase letter in the same row are not significantly different according to Duncan's multiple range test ($P < 0.05$)
"**" means $0.001 < p < 0.01$, "*" means $0.01 < p < 0.05$ and "NS" means $p > 0.05$

The maize yield declined when irrigation and fertilizer reduced, the influence of fertilizer application on yield was very significant, but the influence of irrigation water for production was not significant, and the interaction of irrigation and fertilizer significantly affected on maize yield. The highest maize yield was 7923.02 kg ha^{-1} in HFHW treatment, which was 41.95% higher than CK treatment. The results might be maize did not fully utilize seasonally available water due to percolation below the root zone or water left in the ground at seedling and mature period (Grassini et al. 2009). The other reasons might include the fastest growing stage of maize that had a rapid development during the elongation stage and needed a lot of water and nutrients (Suyker et al. 2005). The highest root and shoot dry weight were obtained in treatment HN4, which might be explained by the high amount of irrigation and nitrogen fertilizationcan meet the increases in air temperature and solar radiation (Romano et al. 2011). In same high irrigation amount, the average maize yield of HF, MF, and LF has increased by 13.85, 17.64, and 24.42 kg per kilogram of nitrogen fertilizer. Results show that under the single factor of fertilization, there was a negative correlation between units increased in yield and unit nitrogen.

3.4 Water Use Efficiency and Harvest Index

Effects of different treatments on harvest index, water production, water use efficiency, and biomass yield of maizeare shown in Table 4. The photosynthetic product quantity was directly on the accumulation of biomass yield, which was also the foundation of into maize yield. The biomass yield was increased with the amount of irrigationand fertilizer. The CK treatment was significantly lower than others, the biomass yield of HFHW treatment was 1.777 times than CK treatment. The results indicated that nitrogen fertilization at 175 kg ha^{-1} (1050 mg/pot) has

Table 4 Effects of different treatments on biomass yield (kg ha^{-1}), harvest index (HI), water production (WP, kg m^{-3}), and water use efficiency (WUE, kg m^{-3}) of maize

Treatments	Irrigation (mm)	Biomass yield (kg ha^{-1})	WP (kg m^{-3})	WUE (kg m^{-3})	HI
CK	0	11,646.25	–	–	0.395
HFHW	200	20,698.12	8.624	3.962	0.383
HFMW	150	16,396.22	9.109	5.067	0.464
HFLW	100	14,256.22	10.560	6.919	0.485
MFHW	200	19,078.87	7.950	3.887	0.408
MFMW	150	15,980.17	8.878	4.982	0.468
MFLW	100	14,678.95	10.873	7.045	0.480
LFHW	200	15,262.15	6.359	3.765	0.493
LFMW	150	13,758.50	7.644	4.394	0.479
LFLW	100	13,556.18	10.042	6.386	0.471

significant increase in plant height, root weight, and biomass in response to inoculation (Gajri et al. 1997; Shaharoona et al. 2006). The optimal growth of maize in semiarid regionsis similar to that in Turkey under two days irrigation frequency and 100% ET water application (Oktem et al. 2003). The same result was observed that the highest biomass yield with 200 mm irrigation amount in the same nitrogen fertilization. The results showed that obvious influence of nitrogen and irrigation on biomass yield, and the interaction of nitrogen and irrigation have significant effects on biomass yield.

The irrigation water productivity was increased with nitrogen application at the same irrigationtreatment, and the water productivity had a negative correlation with irrigation amount under the same fertilizer levels. The results indicated that nitrogen could improve the water production and water use efficiency. The highest water productivity was 10.873 kg m^{-3} in MFLW treatment, and the water use efficiency was 7.054 kg m^{-3}. The relationship of group source and library was harvest index, which may also reflect the Groups of yield components and the accumulation, distribution of the photosynthetic product. There was significant effect of nitrogen and irrigation amount on harvest index, and the harvest index ranged from 0.383 to 0.493. In HF and MF treatment, the harvest index had a negative correlation with irrigation amount, and there was a positive correlation between harvest index and irrigation at the LF levels. Results show that improving the harvest index could achieve strong and sink and source of double effect, finally can achieve the purpose of increasing production.

3.5 Population Physiological Indices

Effects of different nitrogen and fertilizer on population physiological indices of maizeare shown in Fig. 3. At the same levels of fertilizer, the maize yield was positively correlated with irrigation amount. The highest grain yield was obtained in HFHW treatment, and the greatest yield increasing potential was obtained at MFML treatment. There was no significant difference in biomass yield in irrigation treatments, and the highest harvest index was obtained in LFHW treatment. In high irrigation levels, the maize yield, biomass yield, and crop growth rate in HF were 14.51, 45.18, and 60.08% higher than CK treatments, respectively, but the harvest indexwas reduced 21.13%. In high fertilizer levels, the maizeyield, biomass yield, and crop growth rate were increased by 5.22, 35.62, and 34.14% in HF than CK treatments, respectively, but the harvest index was reduced 22.41%. The results show that the population physiological indices of maize were increased with irrigationamount and fertilizer level, except the harvest index. However, the incentive of population physiological indices in irrigation was higher than nitrogen fertilization.

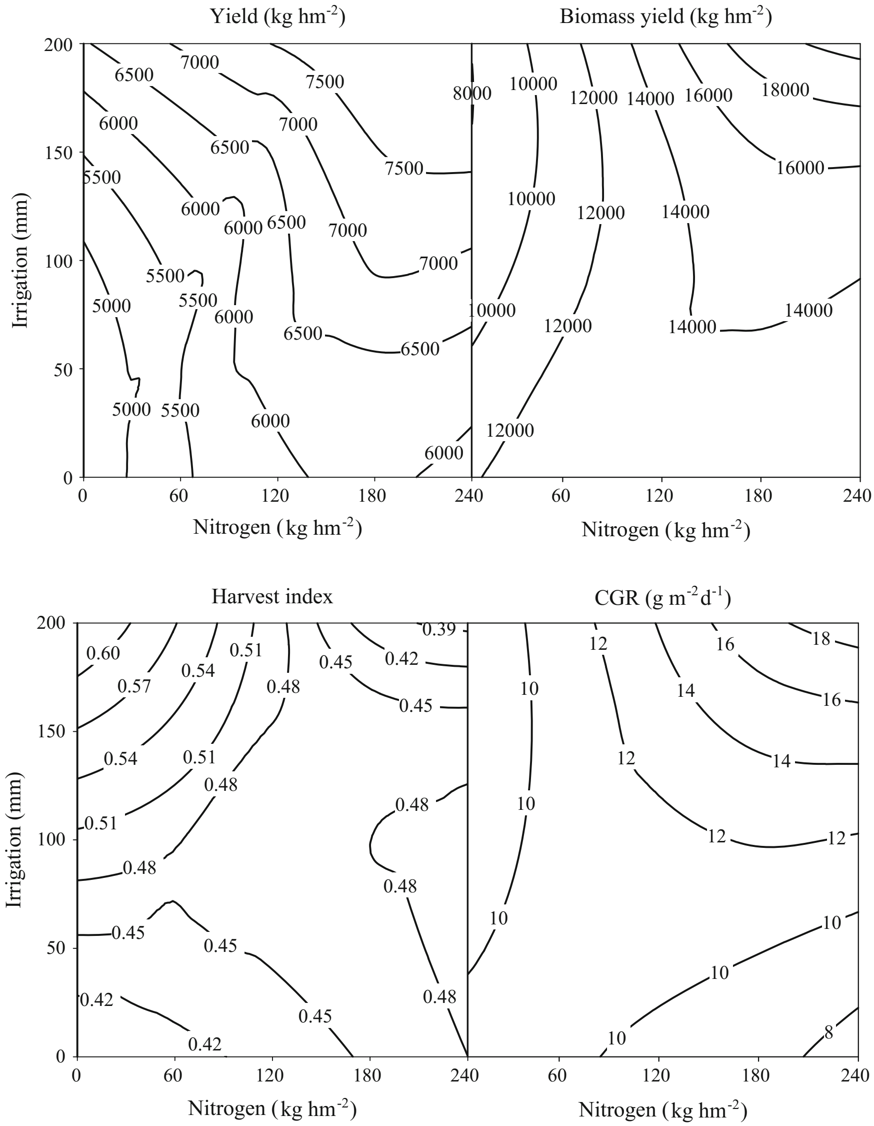

Fig. 3 Effects of different nitrogen and fertilizer on population physiological indices of maize

4 Conclusions

The highest maize yield was 7923.02 kg ha^{-1} in HFHW treatment, which was 41.95% higher than CK treatment. In filling stage, the growth rate of HW and MW treatment was higher 75.76 and 72.21% than CK. The highest water productivity was 10.873 kg m^{-3} in MFLW treatment, and the water use efficiency was 7.054 kg m^{-3}. For these results and more, MFHW treatment may be considered the most efficient for maize production in the rain-fed area of the Loess Plateau, China.

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