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Original Research Article

Long-term continuous spring wheat productivity in semi-arid steppe of North Kazakhstan

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Spring wheat is major crop in northern Kazakhstan occupying about 10 million hectares. Traditionally it is grown in summer fallow-wheat rotations with varying frequency of fallow. Fallow is used for accumulation of water, control of weeds and production of nitrates from organic matter. This practice however leads to soil degradation and should be avoided. In a long-term study at Shortandy site on black soils various fallow-wheat rotations from two year to six year were compared with continuous wheat practice. The objective of the study was to find out influence of long-term wheat growing with various frequency of summer fallow on soil fertility and economics of wheat production. The wheat yield on fallow was higher than on stubble land. However, the annualized wheat grain yield was increased with lengthening of the rotation with the highest yield in continuous wheat - 88% higher as compared to alternate fallow-wheat rotation. During fifty years, the soil organic matter content decreased from 3.90 to 2.48% in two year fallow-wheat rotation as compared to 3.28% in continuous wheat. Continuous wheat is more profitable at medium and high market prices of wheat grain. Continuous wheat growing instead of summer fallow-wheat rotation is suggested. Agricultural policy supporting adoption of No-Till and application of fertilizers should be strengthened to reduce traditionally tilled summer fallow area to minimum. The reduction of tilled summer fallow area is critical to control soil erosion and degradation.

Key words: summer fallow, continuous wheat, annualized wheat production

INTRODUCTION

After plowing 25 million hectares of grassland in Kazakhstan back in 1954-1956 was initially converted into agricultural land and used for continuous spring wheat production. In 1956, a lead soviet scientist A. Barayev visited western Canada and returned back with the idea that frequent summer fallow (with no crop during one year) was the only way to do farming in dryland conditions of north Kazakhstan (Barayev, 1960). At that time in the Canadian prairies monoculture of spring wheat rotated with summer fallow was common farming practice (Hill, 1954). For Canadian farmers advantage of such cropping system was to avoid risk of crop failure in dry years. In fact, alternate fallow-wheat system is not adopted by farmers in northern Kazakhstan. Most widespread system is fallow-wheat rotations with fallow once in 4 years.

The crop rotation study commenced at Shortandy, Kazakhstan in 1961, which includes wheat-fallow rotations with various frequency of the summer fallow. There was also continuous wheat treatment with no fertilizer application. That is why grain-fallow crop rotations had advantage against continuous wheat on annualized grain production at Shortandy (Shramko, 1983). It was even a formula developed of gradual decrease of wheat yield in the fields distanced from summer fallow (Shiyatiy, 1985). For example, the data obtained at the Kostanai station was in accord with this formula (Gilevich, 1987). In this trial wheat grain yield in the first, second and third year after summer fallow was 1.71, 1.36 and 1.09 t ha^{-1} respectively, while in continuous wheat it was 0.85 t ha^{-1}. This kind of data was typical when nitrogen was not applied and weed control on

Table 1. Spring wheat yield as affected by place in crop rotation and frequency of summer fallow, t ha^{-1} (average for 1986-2013)

Crop rotation	Year after fallow					LSD_{05}
	1	2	3	4	5	
Fallow – wheat	1.85					
Fallow - 2 yr wheat	1.85	1.61				0.10
Fallow – 3 yr wheat	1.88	1.74	1.61			0.13
Fallow – 4 yr wheat	1.93	1.67	1.58	1.54		0.15
Fallow – 5 yr wheat	2.05	1.72	1.67	1.63	1.60	0.14
LSD_{05}	0.13	0.10	0.11	0.11		

stubble land was not adequate (Korchagin, 1989; Zhigailov et al., 1989).

Radical change of methodology of crop rotation study at the Shortandy site was made in 1984 when continuous wheat plots started getting necessary fertilizers. Since then annualized grain production from total area including fallow became highest in continuous wheat (Suleimenov, 1988). Similar results earlier were published by Ovsyannikov et al. (1982) in southern forest-steppe zone of Kurgan province, Russia. The idea of possibility of eradicating summer fallow in dryland agriculture however was unanimously rejected by scientists from many parts of the Soviet Union (Buyankin and Burakhta, 1988; Kashtanov, 1988; Korchagin, 1989; Poluektov, 1989; Shiyatiy, 1989; Shramko et al., 1989; Zhigailov et al., 1989). Advocate of summer fallow emphasized on following advantages: better moisture accumulation, better weed control and better nitrate accumulation , higher yield on fallow and yield stability. According to our data summer fallow accumulates 15-20 mm higher moisture as compared to stubble fields (Suleimenov and Akshalov, 2007). In Europe, they are not following summer fallow at all even then they control weeds efficiently. Nitrate accumulation due to summer fallow is true but this practice results in rapid loss of organic carbon and nitrogen. This is one of the reasons of stopping wheat-fallow rotations in western Canada (Gan et al., 2003; Larney et al., 2004).

During 50 years of farming after development of grasslands in northern Kazakhstan organic matter losses on various soil types amounted to 19-22.5% on chernozems, 20-25% on dark chestnut soils and 25-30% on chestnut soils mostly because of soil erosion on summer fallow fields (Suleimenov et al., 2012). In Saskatchewan, Canada by 1970s 35-44% of original nitrogen was lost mostly due to frequent summer fallow (Rennie et al., 1976). The other disadvantage of summer fallow is saline seapage in some areas where salt containing horizon lies not deep and when water is moistening deep soil horizons (Eleshev and Konopianov, 2008). At Shortandy trials it was found that by replacement of summer fallow with oats runoff of snowmelt water in early spring was reduced from 90% to 10% (Suleimenov et al., 2012). It is a unique long-term study in which soil degradation can be observed. Based on short-term data some grain producers find alternate fallow-wheat system more economical (Akayev, 2014; Grinets, 2014). They do not consider long-term effect of frequent summer fallow on soil fertility.

The objective of this paper is to make analysis of a long-term study to compare annualized grain production and economics in continuous spring wheat with different frequency of summer fallow- wheat rotations in order to recommend reduction of area under summer fallow for preventing further soil degradation.

MATERIALS AND METHODS

Northern Kazakhstan is a territory between 50^{o} and 54^{o} N latitude and between 60^{o} and 78^{o} E longitude. It covers the area of 57 million hectares and comprised of four provinces: Akmola, Kostanai, Pavlodar and North Kazakhstan. Experimental site referred to in this paper is Shortandy located at 51.7^{o}NL and 71^{o}EL 60 km away in north of capital Astana.

Soil is heavy clay loam southern calcareous chernozem with organic matter content in arable layer about 3.5%. Long-term average annual precipitation is 322 mm. The distribution of precipitation is characterized by monthly falling of 20-25 mm throughout autumn, winter and spring with more rainfall in June (40 mm), July (54 mm) and August (35 mm). The snowfall takes one third of total annual precipitation and plays an important role in soil moisture accumulation. An annual average air temperature is 2.1^{o}C with the highest temperatures of 20.1^{o}C in July. This type of weather is typical for all northern part of Kazakhstan. In all parts of northern Kazakhstan, application of phosphorus fertilizers at the rate of 15-20 kg P_2O_5 ha^{-1} at the seed sowing is general practice, while application of nitrogen is done at sowing time based on soil analyses (Chernenok and Barkusky, 2014).

A long-term study on crop rotations was commenced in 1961at Shortandy. The fallow-wheat rotations were established with different frequency of fallow: once in 2,3,4,5 and 6 years. Originally continuous wheat was tested with no fertilizer application. However, nitrogen and phosphorus fertilizers were started to apply on continuous

Table 2. Wheat yield and annualized grain production as affected by frequency of summer fallow (average for 1986-2013)

Crop rotation	Yield		Annualized yield	
	t ha^{-1}	%	t ha^{-1}	%
Fallow – wheat	1.85	100	0.92	100
Fallow – 2 yr wheat	1.73	93	1.15	125
Fallow – 3 yr wheat	1.74	94	1.31	142
Fallow – 4 yr wheat	1.68	91	1.35	147
Fallow – 5 yr wheat	1.73	93	1.44	156
Continuous wheat	1.73	93	1.73	188
LSD_{05}	0.11		0.13	

Table 3. Net profit (US$ ha^{-1}) as affected by crop rotations and market prices (average for 1986-2013)

Crop rotation	Cost of production, US$ ha^{-1}	Price, US$ t^{-1}		
		100	200	300
Fallow – wheat	110	-18	74	166
Fallow – 2 yr wheat	140	-25	90	205
Fallow – 3 yr wheat	155	-24	107	238
Fallow – 4 yr wheat	164	-29	106	241
Fallow – 5 yr wheat	170	-26	118	262
Continuous wheat	200	-27	146	319

wheat annually since 1984. In all crop rotations the phosphorus fertilizer was common practice since 1961 at rate of 15 kg P_2O_5 ha^{-1}. From 1984 nitrogen was started to apply annually on all stubble crops including continuous wheat at rate of 35 kg N ha^{-1}. Nitrogen was not applied for crop on summer fallow fields. Traditional stubble mulch tillage by blades was used until 2000 while minimum tillage was used since then. Plot size: length 50 m, width 10 m, in three replications.

Spring wheat yield was determined by harvesting grain by combine. Annualized wheat production means average wheat yield from total area of crop rotation including fallow. Assessment of organic matter content in soil was made by method based on dissolving organic matter to carbonic acid and water (standard GOST 26213). Statistical analysis was made by program AGROS 2.10 (Martynov, 2000).

RESULTS

Grain yield

Spring wheat yields were affected not only by place in the crop rotation but also by frequency of summer fallow (Table 1).

Spring wheat yield increased with lengthening of the rotation. In the first year after summer fallow spring wheat grain yield in a six year crop rotation was 11% higher than in alternate fallow-wheat rotation. This can be explained by remarkable reduction of soil fertility in case of frequent fallowing with no nitrogen applied. In this study in fifty years organic matter content in 0-20 cm soil layer in continuous wheat decreased from 3.90% to 3.26% while in alternate fallow-wheat rotation decreased up to 2.48%. In the second year after summer fallow the wheat yield in six year rotation was 7% higher than in the 3 year rotation. As a result of this an average wheat yield in all crop rotations except alternate fallow-wheat rotation was approximately the same (Table 2).

The same yields in various crop rotations were obtained because wheat yield of the same crop after fallow was higher with lengthening of the rotation. At the same time annualized grain yield from total rotation including fallow increased with reduced frequency of summer fallow and the highest grain production was obtained in continuous wheat.

Economic efficiency

Economic efficiency was determined based on net profit per hectare for crop rotations under different grain prices (Table 3).

Cost of production was the lowest under frequent summer fallow and the highest under continuous wheat. Under low wheat grain prices, which occurs in about 20% of years, all treatments were unprofitable with slight advantage of alternate fallow-wheat system. Under medium grain prices, which happens in about 60% of years, net profit was increased with lengthening of crop rotation and

Table 4. Annualized wheat yield as affected by crop rotations at Shortandy, Kazakhstan and Indian Head, Canada

Crop rotation	Shortandy		Indian Head	
	t ha^{-1}	%	t ha^{-1}	%
Fallow - wheat	0.92	100	1.25	100
Fallow 2 yr wheat	1.15	125	1.58	126
Continuous	1.73	188	2.08	166

continuous wheat was most profitable. The same trend was noticed under high grain prices, which occurs in about 20% of years, with net profit under continuous wheat almost twice the profit under alternate fallow – wheat system. Continuous wheat is more economical as compared to any fallow-wheat rotation.

Policy suggestions

Summer fallow area in northern Kazakhstan has been reduced in recent past ten years from 3 to 1-1.5 million hectares (Ministry of Agriculture, 2014). This became possible due to good extension work done by researchers of the Scientific Production Center of Grain Farming named after A.I. Barayev with support by Ministry of Agriculture. However, still there is a large area of summer fallow with traditional tillage which is subjected to soil erosion. The Ministry of Agriculture pays subsidies to farmers for adoption of No-Till and application of fertilizers. Incentive should also be given to farmers to promote continuous wheat growing so that summer fallow with traditional tillage practice can be reduced to minimum.

DISCUSSION

In Kazakhstan, advantage of continuous wheat over wheat-fallow crop rotations on annualized grain production shown in this paper may seem to be very high. But there is a good similarity between our data and the data generated at the Indian Head station, Saskatchewan, Canada based on same kind of research during 1958-2007 for annualized wheat production (Lafond et al., 2012) (Table 4).

The per cent annualized wheat grain production in both the study are quite closer under fallow – 2 year wheat rotation. The advantage of continuous wheat at Shortandy station is higher possibly because of higher losses of organic matter in fallow – wheat rotation and no nitrogen applied on summer fallow. At the Indian Head station after 50 years soil organic carbon content in 0-15 cm layer in fallow–wheat and continuous wheat was 32.84 and 38.24 t ha^{-1} , respectively (Lafond et al., 2012). In another long-term crop rotation study at Swift Current, a 36 year average wheat yield on fallow was 36% higher compared to stubble land crop. The annualized wheat yield however was 40% higher on continuous wheat (Lemke et al., 2012). These results may not be obtained in on-farm conditions immediately because on many farms of northern Kazakhstan nitrogen fertilizers are not applied. For that reason some people stick to summer fallow once in three years (Shiyatiy, 1996) and even to alternate summer fallow-wheat system (Akayev, 2014; Grinets, 2014). Suleimenov et al. (2010) suggested the possibility of replacing summer fallow with food legumes. This practice is supported by other research data (Yushchenko, 2014) as well as adopted by some farmers at Karaganda province (Prokop, 2014).

CONCLUSION

Fallow-wheat crop rotations with various frequency of fallow are generally adopted farming practice in northern Kazakhstan. The long-term experiment conducted at Shortandy site showed considerable advantage of reduced frequency of summer fallow on annualized grain production with best results obtained on continuous wheat. Annualized grain production was 88% higher in continuous wheat as compared to alternate fallow-wheat rotation.

After fifty years of study, it was observed that alternate fallow-wheat rotation resulted in significant loss of soil organic matter. Continuous wheat is more profitable under medium and high market prices on spring wheat grain. At market prices US$ 200 and 300 t^{-1} net profit per hectare of continuous wheat amounted to US$ 146 and 319 respectively against US$ 74 and 106 in alternate fallow-wheat rotation.

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