EFFECT OF FALLOWING ON SOIL ORGANIC MATTER CHARACTERISTICS ON WHEAT MONOCULTURE IN ARID STEPPES OF NORTHERN KAZAKHSTAN

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Abstract

Chernozem soils of dry steppe regions in Northern Kazakhstan are the most productive soils that produces high quality grains. Dry climate of the region limits mineralization of soil organic matter; therefore, a fallow year is usually introduced in monoculture of wheat, aimed to retain more mineral N and moisture. However, often fallowing may cause the excess losses of nutrients due to accelerated mineralization. A long-term replicated crop rotation experiment initiated in 1950's at the Research Institute of Grain Farming; Kazakhstan provided a unique opportunity to examine impact of fallowing on soil organic matter quality. The objective of this work, therefore, was to compare the relative effects of fallow on soil characteristics on chernozem soils from different stages of the crop rotation and from three different sites.

Keywords: fallow, soil organic matter, mineralization, nitrogen

INTRODUCTION

The depletion of soil organic matter has been cited as a serious threat to the maintenance of soil productivity in semiarid regions. The organic matter content and nutrient supplying capability of many soils in the North Kazakhstan have declined since they were initially cultivated. Previous works evaluating effects of cultivation on soil quality in the U.S., Canadian prairies and steppes of North Kazakhstan have shown that cultivation substantially reduces organic matter quantity and quality (Aguilar et al., 1988; Titlyanova et al., 1984; McGill et al., 1988).

Chernozem soils in North Kazakhstan occupy 25.3 million ha (Borovski and Uspanov, 1971) and are the most productive soils of the country. Under monoculture cropping of spring wheat with no fertilizer application, the N requirements of crops have been met by mineralization of soil organic matter in the preceding cultivated fallow. Such farming system are exploitative and there is a need for research into the development of sustainable systems in which organic matter levels can be maintained and even increased for chernozems in semiarid zone of northern Kazakhstan. Although, the inclusion of summer fallow into rotation is wide spread in semiarid zones of northern Kazakhstan, recently scientists raise the problem of negative effect of fallowing to soil fertility. Some researchers have demonstrated that fallowing significantly exacerbates the depletion of organic matter (Ferguson and Gorby, 1971; Clarke and Russell, 1977; Dormar, 1983). Biederbeck et al., 1984), also observed that levels of potentially mineralizable N were significantly higher in continuous wheat than in wheat-fallow treatments after 16 years of cropping. Janzen (1987), reporting the results of his study on Canadian soils, noted, that the organic C and N content of soil after 33 y of cropping decreased with increasing frequency of fallow in the rotation. Also, Campbell et al., (1992b), reported that crop residue and residue C and N returned into the soil over the 23 years period were considerably greater for continuous wheat than for the other rotations, was lowest for the 2 y, fallow-corn rotation.

Organic C and N retention in soil is influenced by crop rotation (Biederbeck et al., 1984), tillage (Campbell and Souster, 1982; Lamb et al., 1985), residue management (Rasmussen et al., 1980) and fertility (Biederbeck et al., 1984; El-Haris et al., 1983; Rasmussen et al., 1980).

In chernozemic areas of Northern Kazakhstan a long-term replicated crop rotation experiment initiated in 1950’s at the Research Institute of Grain Farming; Kazakhstan provided a unique opportunity to examine effects of spring wheat rotations and cultural practices on soil organic matter quality. Thus, the objective of this work, therefore, was to compare the relative effects of fallow on soil characteristics on chernozem soils of northern Kazakhstan from 4 different sites.

MATERIALS AND METHODS

Site characteristic and soil sampling

The territory of Northern Kazakhstan is situated between 50 and 55^{o} latitude and occupies 600,000 km^2. The climate in North Kazakhstan is continental and dry with abrupt changes of temperature, moisture, amount of precipitation and other climatic indices. Average annual precipitation at the experimental sites is between 250-380 mm. The 70% of the yearly precipitation falls between April-October. Precipitation in winter occurs more frequent than in summer, however their amount is less. Total yearly precipitation is not enough for optimal crop growth in most of the sites. Maximum efficient precipitation falls in summer, but summer is still dry. Landscape of the territory is mainly plain. Within North Kazakhstan 3 experimental sites was selected (Fig. 1).

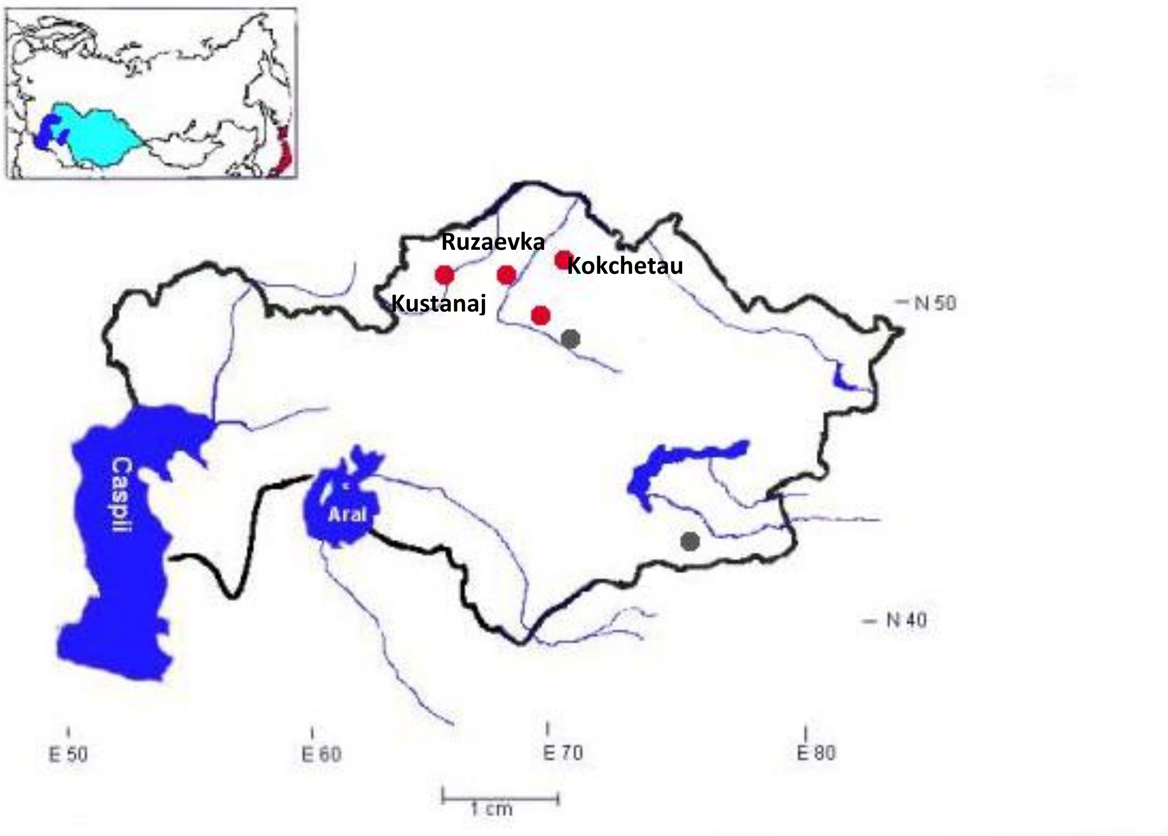

Figure 1. Experimental studied sites

Soil sampling was performed from different phases of crop rotations in order to reveal short term effect of fallowing on soil characteristics. From each site the most typical crop rotation systems were chosen. In Kokchetau, the phases before and after fallowing (R1 and R4) in a 5-year crop rotation were sampled. In Ruzaevka, the same phases were sampled and additional continuous fallowing (standard tillage without planting) (CF) and continuous cropping of spring wheat (CW) were sampled. In Kustanai, two crop rotations were selected: 4-year and 7-year, where, the 1st year and the 4th year after fallow were sampled, and a continuous spring wheat planting plot was sampled as well (Table 1).

Analytical methods

Air-dried soil samples, sieved through 2mm were prepared and stored in plastic bottles for further analysis. Analytical items and methods are described as follows:

General soil agrochemical properties: Soil pH (H_2O) was measured with a glass electrode pH meter. Electrical conductivity (EC) were done by a EC meter (TOA, CM-5B). Exchangeable cations (Ca, Mg, K, Na) were extracted from the soils by 1*N* ammonium acetate solution (pH 7) after being shaken for one hour.

Table 1. Sampling plots in three studied experimental sites

Kokchetau	Ruzaevka	Kustanai
R1: after fallow, F*WWBW.	R1: after fallow, F*WWBW	R1: after fallow, F*WWW.
R4: before fallow, FWWBW*****.	R4: before fallow, FWWBW*****	R3: before fallow, FWWW*****.
CW: Continuous cropping of spring wheat.	CW: Continuous cropping of spring wheat.	CW: Continuous cropping of spring wheat.

Note: F-fallow; W-spring wheat; B-barley; CW-continuous cropping; CF-continuous fallow; A-alfa-alfa; R1-first year after fallow; R4-fouth year after fallow, or the year before fallow; R3 after three years from fallow or the year before fallow; ***-**sampling year.

Soil to solution ratio was 1 to 5. Exchangeable Ca and Mg were determined using atomic absorption analyser, and exchangeable K and Na by flame emission spectrophotometer (Shimadzu AA-640-12). Cation exchange capacity (CEC) was determined after replacement of exchangeable cations in residual soils and after the soils was washed with deionized water and ethanol solution successively to remove the excess ammonium. Absorbed NH_4-N was extracted with 10% NaCl solution, and measured by the Kjeldahl distillation method. After extraction of exchangeable cations, the residual soils were used to determine CEC. After being washed with deionized water and ethanol solution successively to remove the excess ammonium, absorbed NH4 was extracted with 10% NaCl solution, and measured by distillation method. Total N and total C were determined by dry combustion method using NC-auto-analyser (Sumika NC-800-13N). Organic C was measured by acidification of organic C of the soil by excess amount of potassium dichromate, where excess dichromate was titrated by Mohr's Salt. By subtracting the volume of dichromate before and after acidification the amount of organic C was calculated.

Determination of mineralizable nitrogen by colorimetric method: Mineralized N was determined after incubation of soils for 2-, 4-, 6-, 8-, 10-weeks and analysed for nitrate and ammonium N content by colorimetric method following extraction with 2*N* KCl solution. Nitrate N was analyzed after reduction of NO_3 ions to NO_2 by passing the extraction through cadmium column Ammonium N was analyzed by salicylate nitroprusside method (Keeny and Nelson, 1982).

Statistical analysis: All variables were subjected to a one-way analysis of variance to determine the significance of treatment effects (SPSS, 1998a). Where significant treatment effects were observed ($P<0.05$), *LSD* analysis was performed to permit separation of means.

RESULTS

General soil characteristics of the sites

Kokchetau Experimental Site had an average soil pH 8.0 and EC 160 micro S cm^{-1} in 0-30 cm soil layer. Exchangeable cations consisted of 81% of Ca; 12% of Mg, 4.6% of K and 2.4% of

Na in average in 0-30 cm soil layer. Average CEC was 15 cmol kg^{-1} soil. Among treatments there was observed a lower concentration of Ca accumulated under continuous wheat treatment.

Ruzaevka experimental sites had an average soil pH 8.2 and EC 179 micro S cm^{-1} in 0-30 cm soil layer. Exchangeable cations in Ruzaevka consisted of 85% of Ca; 9.1% of Mg, 4.9% of K and 1% of Na in average in 0-30 cm soil layer. Average CEC was 14 cmol kg^{-1} of soil. Generally, distribution of Mg, K and Na in three soil layers was like those in Kokchetau. Between treatments there was a little lower amount of Ca in rotation than in continuous wheat and fallow treatments.

Kustanai experimental site characterized with light textured soils. Therefore, the values of pH, EC and concentration of exchangeable cations were different from others. The average pH was 6.3 and EC was 35.3 micro S cm^{-1} of soil. Cations distributed as follow: Ca-77%; Mg-16.5%; K-5.5% and Na was 0.9%. The average CEC was 8.2 cmol/kg of soil.

Effect of Cropping Frequency Treatment on Soil Organic Matter

The amount of soil organic matter (SOM) generally showed approximately similar levels in the 0-10 cm soil layers of Kustanai and Kokchetau sites, while Ruzaevka soils maintained higher content of both organic C and total N. Between treatments, statistically significant differences in the amount of total and organic C were found for Kustanai and Ruzaevka sites. The first year after fallow and the continuous cropping of wheat showed similar values (Tables 2,3,4). Variation in the content and distribution of SOM content between the experimental sites is attributed to the differences in soil characteristics and climatic zone. Kustanai experimental site characterized with light textured sandy soils with average soil pH 6,2 (H_2O) and with a little greater amount of precipitation. Under these conditions SOM subjected to a greater loss through mineralization.

DISCUSSION

About half a century ago Alison and Sterling (1947) reported that in a given soil type and under similar climatic conditions, thoroughly humified soil organic matter is fairly uniform in quality regardless of past agronomic treatment. The total nitrogen content under these conditions appears to be a rough index of the nitrate-furnishing powers of variously treated soils.

Table 2. Soil organic matter in Kustanai

	Total N (%)	Total C (%)	Organic C (%)	C/N
		0-10 cm		
R1	0.130a	1.68a	1.61a	12.4
R4	0.176b	2.32b	2.14b	12.2
CW	0.230c	2.30b	2.25a	9.80
		10-20 cm		
R1	0.123a	1.55a	1.27a	10.4
R4	0.176b	2.32b	2.14b	12.2
CW	0.230c	2.30b	2.25b	9.80
		20-30 cm		
R1	0.098a	1.30a	1.10a	11.15
R4	0.106a	1.28a	1.30a	12.3
CW	0.140b	1.75ab	1.51a	10.8

R1 - first year after fallow; R4 - forth year after fallow; CW – continuous cropping of wheat

Table 3. Soil organic matter in Kokchetau

	Total N, %	Total C, %	Organic C, %	C/N
		0-10 cm		
R1	0.21a	2.72a	2.22a	10.5
R4	0.22a	2.68a	2.00a	9.2
CW	0.24a	2.70a	2.21a	9.2
		10-20 cm		
R1	0.21a	2.62a	2.32a	11.3
R4	0.19a	2.17b	2.16a	11.5
CW	0.17b	1.91b	1.82b	10.7
		20-30 cm		
R1	0.17b	2.24b	1.77b	10.3
R4	0.17b	2.11b	1.50b	8.8
CW	0.14b	1.69b	1.29b	9.4

R1 - first year after fallow; R4 - forth year after fallow; CW – continuous cropping of wheat

Table 4. Soil organic matter in Ruzaevka

	Total N (%)	Total C (%)	Organic C (%)	C/N
		0-10cm		
R1	0.30a	3.62a	3.19a	10.6
R4	0.30a	3.63a	2.30b	7.6
CW	0.30a	3.67a	3.00a	10.0
		10-20cm		
R1	0.29a	3.51a	3.14a	10.9
R4	0.29a	3.50a	2.96a	10.3
CW	0.28a	3.50a	2.70b	9.8
		20-30cm		
R1	0.26a	3.28a	2.72b	12.1
R4	0.25a	3.21a	2.41b	9.8
CW	0.23ab	3.20a	2.20b	9.6

R1 - first year after fallow; R4 - forth year after fallow; CW – continuous cropping of wheat

Generally, many of alternative studies showed that the more dynamic soil characteristics such as mineralizable N and microbial biomass, respond more rapidly and strongly to crop management changes than do characteristics such as total soil organic matter (McGill et al., 1988). Also, Campbell and Souster (1982) reported that in the chernozemic soils, the loss of potentially mineralizable nitrogen is even greater than the loss of gross organic matter. However, the extent of the effects of agricultural practices depends on the *soil zone* (Campbell et al., 1991a), *initial level of soil organic matter* (McGill et al., 1981), *amount of the crop residues* returned to the soil and *C-to-N ratio* (Campbell 1978; Campbell et al., 1991a, b).

N mineralization is often measured to assess the capacity of soil organic matter to supply inorganic N, mainly NO_3, which is the main form of plant-available N and mobile N that leaches through the soil (Gregorich et al., 1994).

Effect of fallow on mineralizable N in Kokchetau site

There was observed a tendency of increasing mineralized N with time distance from fallowing in the 0-10 and 10-20 cm soil layers. First year after fallow maintained the least mineralized N and continuous cropping maintained the greatest amount of mineralized N. The fourth year after fallow (R4) was intermediate. There are several possible reasons. One is that, during fallowing mineralized N is partly subjected to losses through leaching, volatilization, as well as through physical erosion, and because no plant uptake in fallow year more N losses occurs under fallowing. And by the sampling time, lesser amount of mineralizable nitrogen remained in the soil. The first crop grown immediately after fallowing gains all the advantages of the nutrition and moisture accumulated during the bare fallowing. But in case of continuous cropping there was not breaking in cropping thus no break in receiving plant residues. If non-humified plant residues consists of easily mineralizable organic substrates, the amount mineralizable N in continuous cropping treatment is constantly replenished by labile OM.

Table 5. Mineralizable N in Kokchetau experimental site

Phase of rotation	Depths of sampling, cm		
	0-10	10-20	20-30
R1	15.55a	16.49a	4.87a
R4	21.64b	17.12a	15.14b
CW	28.75c	20.53b	14.00b

R1 – first year after fallow; R4 – forth year after fallow; CW – continuous cropping of wheat

Soil organic matter is buildup of different fractions varying from very active to passive, both chemically and biologically. It is useful to identify the fractions that are most sensitive to management practices. It is generally agreed that this labile fraction is largely made up of plant debris but also contains microbial and microfaunal products (Dalal and Mayer, 1986; Janzen et al., 1992). It is a part of labile fraction and microbial biomass serves as a processor for N transformation from organic substrates of labile pool to mineral N, which is a nutritive source for plants. In the case of no additional inputs to this system a part of SOM is supposed to be mineralized into labile fraction supplying plants with nutrients, which after certain time span may result in SOM deterioration. In contrast, under some agricultural practice plant residues and fertilizer application make additional inputs for labile pool, thus preventing SOM depletion, as well as increasing crop production. Wheat straw residue frequently reaches 3000 kg/ha in fresh biomass. While during the fallow period, which extends approximately 21 months and spans two winters, there is no residue income into the soil. But at the same time fallowing field must be repeatedly harrowed to control weeds that are the greatest problem in fallow. As few as three soil tillage operations are needed to control weeds in fallow in arid areas of northern Kazakhstan. Such intensive cultivation of bare field causes accelerated mineralization of SOM. And mineralized nitrogen is subjected to losses through erosions and leaching. In some instances, in an extremely dry situation, some of the N may be lost by ammonia volatilization. Or, if an unusually wet winter is experienced, leaching could lose nitrates. Available information also indicates that, frequently, even in dryland soils, about 20% of the N applied may be lost by denitrification.

Thus, the fallowing breaks successive plant residue input into a soil resulting in number of undesirable occurrences. Among the main disadvantages of the summer fallow some researcher are indicating these: 1) low rate of precipitation intake. 2) poor conservation of crop stubble on the soil surface and a large probability of wind erosion occurrence. 3) accelerated humus mineralization, excessive nitrate accumulation and occurring of biological erosion of soil (Moshenko and Silantiev, 1992)

Good management of dryland soils mandates the use of practices that reduce evapotranspiration losses to the greatest extent possible, especially during vegetation periods, through keeping as much residue cover on the soil as possible to reduce evaporation and runoff losses, as well as loss of nutrients through soil erosion. This goal can be achieved through adequate management of fallowing, ie., length of the crop rotation and frequency of fallowing.

Acknowledgement

This research was partially supported by the Ministry of Education and Science and Technological Development of the Republic of Serbia, Project TR37006.

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