Chapter 14
Sustainability of Soil Fertility in the Southern Steppe of Ukraine, Depending on Fertilizers and Irrigation

Valentyna Gamajunova

Abstract Farming in the Southern Steppe of Ukraine is mining humus and nutrients. There comes a point when soil degradation is irreversible: sustainability requires complying with the fundamental laws of agriculture—in particular, sound crop rotation and return of nutrients to balance removal by the crops. Short- and long-term field experiments on typical *Kastanozen* and *Chernozem* reveal that provision of adequate nutrients and water gives consistently high crop yields and these factors significantly change the main indicators of soil fertility: humus content, gross and moving content of NPK, and water–physical properties (as well as the content of arsenic and heavy metals). Combined use of organic and mineral fertilizers is the most effective way to stabilize crop yields and soil fertility; organic fertilizers stabilize soil structure which, in turn, enhances the infiltration of rainfall. Combined organic–mineral fertilizer in crop rotation increases the efficiency of water utilization on average by 20–30%, in very dry years by 30–40%.

Keywords *Kastanozem* · *Chernozem* · Humus · Soil nutrients · Fertilizer regime · Sustainability

Introduction

Judged by any indicator of soil fertility, Ukraine is the richest country in the world. But while the soil is the main means of production and must be used, it should also be conserved. In developed countries, legislation spells out the inadmissibility of land degradation that leads to a loss of soil function, productivity and ecosystem services but, in Ukraine, no one takes responsibility for land degradation—indeed, the government has suspended programs to improve soil fertility (Baliuk 2014).

V. Gamajunova (✉)
Mykolayiv National Agrarian University, 9 Paryzka Komuni St,
Mykolayiv 54020, Ukraine
e-mail: gamajunova2301@gmail.com

D. Dent and Y. Dmytruk (eds.), *Soil Science Working for a Living*,
DOI 10.1007/978-3-319-45417-7_14

The productivity and economic efficiency of the farming system depend on the structure of the sown area and crop rotation. A sound rotation, in which each crop is grown following the best predecessor, is the most important element in maintaining soil fertility—increasing the productivity of arable land by 15–20% without any additional costs. Fertilization according to the special needs of each crop in rotation reduces costs and contains weeds, pests and diseases—without resorting to chemical means of protection; soil fertility and soil moisture are conserved; and biological nitrogen is accumulated by legumes.

Research has established that to maintain soil fertility in the Southern Steppe zone of Ukraine, each hectare of crop rotation needs to generate, annually, 7–8 t of organic matter and 80–100 kg of nutrients under rain-fed farming and 12–15 t/ha and 240–260 kg/ha, respectively, under irrigation. Such productivity is not achieved nowadays. In recent years, farming has been mining residual humus and nutrients; the soils are more and more degraded, and there comes a point when degradation processes are irreversible. Arresting soil degradation means observing the fundamental laws of agriculture—in particular, the law of returning nutrients to the soil by the application of mineral and organic fertilizers to balance removal by the crops. Moreover, fertilization is the most effective factor for crop yield and, also, improves the quality of the crops (Dobrovolsky 2001; Filip'yev et al. 2009).

The yield deficit also arises from insufficient rainfall or, rather, unproductive water loss—an increasingly serious issue the context of global warming. As the vast majority of farms have shunned a sound crop rotation, neglecting the legumes and grasses in favor of sunflower cultivation, we have observed wastage of humus and loss of soil structure that inhibits the infiltration of rainfall and accumulation of water reserves in the soil (Krutya and Tarariko 2000).

In itself, optimum fertilization contributes to the efficient utilization of soil moisture by crops. Long-term trials show that water consumption by unfertilized winter wheat is 526 m^3 per tonne of grain, whereas with complete fertilizer, consumptive use of water is 336 m^3/t–36% less than the unfertilized control (Gamajunova 2004). Similarly, optimal supply of nutrients reduces the consumptive use of water to produce a unit of dry matter of corn and sugar beet by 20–25% compared with the soils of low nutrient security. Variable weather may cause annual fluctuations of crop yields within ±40–50%, but these fluctuations are much less when soil fertility is maintained.

Field Experiments

To provide reliable data and determine changes in the main indicators of soil fertility and crop productivity, long-term and short-term field experiments have been undertaken on typical dark brown earth (*Kastanozem*) and black earth (*Chernozem*) on irrigated fields of the Institute of the National Academy of Agrarian Sciences of Ukraine and Mykolayiv National Agrarian University, respectively.

Table 14.1 Humus content in the 0–30-cm layer of dark brown soil under fertilization and irrigation

Variant of experiment	Humus content (%)		Humus loss or gain	
	Initial	After 4th rotation	Absolute (%)	Mean annual (kg/ha)
Without fertilizer	2.26	2.11	−0.15	−277.5
P_2O_5	2.26	2.19	−0.07	−129.5
N	2.26	2.23	−0.03	−55.5
NPK	2.26	2.25	−0.01	−13.5
NPK + 80 t/ha farmyard manure per rotation	2.26	2.35	+0.09	+166.5

Trends of Topsoil Humus Content

On the *Kastanozem* of the Ingulets irrigation system, after four rotations of a 7-field rotation that includes 36% lucerne, the annual loss of humus from the topsoil of unirrigated soil amounted to 70–90 kg/ha—somewhat more under irrigation. Humus content was maintained by the application of complete fertilizer (Table 14.1).

Trends of Crop Yield

Fertilizer application influences soil physical properties, microbiological activity, and the content of micronutrients. In turn, the soil's nutrient status significantly affects both crop yields and quality, both with and without irrigation. Irrigated crops, producing higher yields, require more nutrients. This is illustrated in Table 14.2 which summarizes the results. Again, we see that provision of adequate nutrients and water gives consistently high crop yields and these two factors significantly change the main indicators of soil fertility: humus content (Table 14.1), gross and moving content of NPK, and water–physical properties.

Trends in Arsenic and Heavy Metals

It is known that arsenic and heavy metals are added to the soil with fertilizer; in the case of arsenic in nitrogen fertilizer—the quantity varies from 2.2 to 120 mg/kg (Karpova 1991). Irrigation water can also pollute where the arsenic content exceeds the maximum allowable concentration. Soil samples were selected from 20-cm increments to a depth of 1 m in June 2001. Total arsenic was extracted with 0.2 M HCl and determined by arsenic–molybdenum blue after removal of arsenic in the

Table 14.2 Productivity of crop rotation depending on irrigation and fertilizers

Variant	Productivity of crop rotation c/ha fodder units				Over 30-year period	Increase %		
	I	II	III	IV		From fertilizers	From irrigation	From irrigation and fertilizers
Without irrigation or fertilizer	$\frac{337.1}{42.1}$	$\frac{360.5}{45.1}$	$\frac{251.4}{35.9}$	$\frac{223.9}{32.0}$	$\frac{1173}{39.1}$	–	–	–
Without irrigation + NPK_1	$\frac{394.7}{49.3}$	$\frac{455.9}{56.7}$	$\frac{265.4}{37.9}$	$\frac{244.7}{35.0}$	$\frac{1359}{45.3}$	15.9	–	–
Without irrigation + NPK_2	$\frac{408.3}{51.0}$	$\frac{489.2}{61.2}$	$\frac{267.6}{38.2}$	$\frac{233.4}{33.3}$	$\frac{1398}{46.6}$	19.2	–	–
Irrigation, without fertilizers	$\frac{428.8}{53.6}$	$\frac{414.9}{51.9}$	$\frac{450.0}{64.3}$	$\frac{369.0}{52.7}$	$\frac{1663}{55.4}$	–	41.7	–
Irrigation + NPK_1	$\frac{506.0}{63.3}$	$\frac{566.8}{70.9}$	$\frac{563.8}{80.5}$	$\frac{501.5}{71.6}$	$\frac{2138}{71.3}$	28.7	57.4	182.3
Irrigation + NPK_2	$\frac{698.1}{87.3}$	$\frac{659.0}{82.4}$	$\frac{599.1}{85.6}$	$\frac{551.7}{78.8}$	$\frac{2508}{83.6}$	50.9	79.4	213.8

Above the line—the amount per crop rotation; below the line—in an average year
NPK_1—recommended dose of fertilizers for each rotation culture for rain-fed conditions
NPK_2—the same conditions for irrigation

form of arsine and its subsequent oxidation of iodine solution and measuring the absorbance of the complex relative to a reference solution for wavelength $\lambda = 750$ nm. The experimental data demonstrate that the amount of total and mobile arsenic is increased by systematic application of increasing doses of mineral fertilizers (Table 14.3).

Irrigation without fertilizers had almost no effect on the content of mobile forms of arsenic. However, the total arsenic content of both 0–20 and 0–100-cm irrigated soil was lower than the rain-fed analogue (1.35 and 0.92 as opposed to 1.71 and 1.42 mg/kg, respectively, in Table 14.4). This reduction in the arsenic content in soil under irrigation may be connected with higher crop yields (Table 14.2) and enhanced removal of chemical elements by these crops.

Table 14.3 Arsenic in the 0–20-cm layer of dark brown soil after 30 years of irrigated crop rotation

Variant of experiment	Arsenic (mg/kg)			
	Without irrigation		Irrigated	
	Total	Mobile	Total	Mobile
Fallow (background content)	0.98 ± 0.05	0.03 ± 0.001	0.98 ± 0.05	0.03 ± 0.001
Without fertilizer	1.35 ± 0.06	0.07 ± 0.002	0.92 ± 0.03	0.06 ± 0.002
$N_{90}P_{60}K_{30}$	2.15 ± 0.06	0.05 ± 0.001	2.15 ± 0.09	0.37 ± 0.020
$N_{150}P_{90}K_{60}$	3.10 ± 0.16	0.10 ± 0.005	3.40 ± 0.17	0.54 ± 0.020

Table 14.4 Total arsenic accumulation in soil layers, depending on irrigation and fertilizers

Soil layer (cm)	Total arsenic, mg/kg soil						
	Fallow (background)	Without irrigation			Irrigated		
		Without fertilizer	$N_{90}P_{60}K_{30}$	$N_{150}P_{90}K_{60}$	Without fertilizer	$N_{90}P_{60}K_{30}$	$N_{150}P_{90}K_{60}$
0–20	0.98	1.35	2.15	3.10	0.92	2.15	3.40
20–40	2.05	1.55	2.40	2.50	1.75	2.55	1.75
40–60	1.20	1.40	2.70	2.75	1.45	2.30	2.75
60–80	1.55	1.75	1.75	1.55	1.55	1.55	1.38
80–100	0.92	0.98	1.95	0.98	1.45	1.55	0.92
0–100	1.34	1.41	2.19	1.98	1.42	2.02	2.04
Least significant difference	0.17	0.17	0.27	0.26	0.17	0.23	0.21

Table 14.5 Water-absorbing capacity of soil depending on organic fertilizers (means 2008–2010)

Variant experiment	Infiltration (mm/h)	% compared with control
Without fertilizers	11.69	100.0
Manure 30 t/ha	13.60	116.0
Green fertilizer (peas)	15.30	130.9
Green fertilizer (rape)	14.73	126.0

Trends in Available Water

Combined use of organic and mineral fertilizers is the most effective way to stabilize crop yields and increase soil fertility. Organic fertilizers contribute to increased yields in dry years by providing reactive humic substances that stabilize soil structure which, in turn, enhances infiltration of rainfall. Combined organic–mineral fertilizer in crop rotation increases the efficiency of water utilization on average by 20–30%, in very dry years by 30–40%.

Nowadays, farmyard manure is hardly available, so, as an alternative, we investigated cereal straw and green manure. Straw was incorporated in the topsoil immediately after harvesting winter wheat, stubble-seeded oats/pea mixture for the green mass, and maize. Table 14.5 shows the beneficial effect on water infiltration and water retention by the soil.

Over 3 years of growing maize, compared with the unfertilized control, prior application of 30 t/ha farmyard manure increased the soil water by 25.6%; straw incorporation at 6 t/ha increased soil water by 34.6%. The residual effect under the following winter wheat crop was an increase of 16.3% from farmyard manure and 22.8% from straw incorporation. These data indicate that maintenance of soil organic matter is essential to maintain the soil's infiltration capacity and water retention capacity. In itself, the water-holding capacity of organic matter is 5–10 times higher than the mineral fraction of the soil, but the greater benefit comes from the maintenance of a stable crumb structure. Incorporating straw, cornstalks, and green manure is more effective than adding farmyard manure.

Postharvest crop residues distributed on the fields accelerate the infiltration of water and arrest runoff. Earlier research (Gamajunova 2006) showed that incorporation of straw into the soil increases the accumulation of moisture in the topsoil by 15–20% compared with no incorporation of straw.

Combined Effects

Many studies have shown that improving the soil nutrient regime and availability of moisture by applying fertilizer increases crop yields. Table 14.6 shows the example of *soriz* (grain sorghum) grown in different crop sequences in crop rotation where,

Table 14.6 Effect of fertilizers and predecessors on the yield of soriz, t/ha

Field crop rotation (factor A)	Background supply (factor B)								
	Without fertilizer			Straw + $N_{60}P_{40}$			$N_{60}P_{40}$		
	2004	2005	2006	2004	2005	2006	2004	2005	2006
Peas–winter barley–soriz	4.26	3.18	3.30	5.29	4.41	4.50	5.42	4.55	4.61
Sunflower–winter barley–soriz	4.05	2.98	3.11	5.00	4.09	4.16	5.14	4.22	4.28
Maize–winter barley–soriz	4.06	3.01	3.13	5.17	4.23	4.30	5.27	4.33	4.40
Winter barley–maize–soriz	3.95	2.88	3.02	4.92	3.93	4.12	5.12	4.16	4.24
Winter wheat–sunflower–soriz	3.81	2.70	2.82	4.82	3.92	4.10	5.09	4.11	4.20
Average for factor B	4.03	2.75	3.08	4.84	4.12	4.24	5.21	4.27	4.35
Least significant difference $_{05}$, t/ha	*2004 p.*			*2005 p.*			*2006 p.*		
Factor A	0.071			0.051			0.12		
Factor B	0.084			0.098			0.19		
Combination of factors A and B	0.130			0.270			0.21		

after harvesting cereals, the straw is incorporated into the soil as organic fertilizer (Table 14.6).

The average grain yield of *soriz* with all predecessors without fertilizers is 3.35 t/ha. With the combined use of a link of crop rotation and organic fertilizer (such as ploughing in chopped straw after harvesting) and application of recommended dose of fertilizer ($N_{60}P_{40}$), the yield is raised to 4.46 t/ha, an increase of 1.11 t/ha or 33% compared with the unfertilized control. Application of $N_{60}P_{40}$ without straw raised the grain yield to 4.61 t/ha, an increase over the control of 1.26 t/ha or 36.7%. The lesser yield associated with straw application is associated with the uptake of nutrients, especially nitrogen, by microorganisms that decompose the organic matter. However, the temporarily fixed nutrients subsequently become available to plants through the mineralization of the straw and microbial organic matter. The highest crop yields were recorded the relatively wet year of in 2004 but the benefit of fertilizer is seen even more in dry years, which indicates more efficient use of water by fertilized plants.

And it should be noted that combined organic and mineral fertilizers also significantly improve the quality indicators of farm produce.

References

Baliuk SA (2014) Recommendations of the Ukrainian Society of Soil Scientists and Agro-Chemists 2010–2014: Urgent Tasks for the Future. In: Agricultural Chemistry and Soil Science—special issue on the IX Congress of the Ukrainian Society of Soil Scientists and Agro-chemists, Plenary lectures: protection of soil—the basis of sustainable development of Ukraine, Kharkiv, vol 1, pp 3–17 (Ukrainian)

Dobrovolsky GV (2001) Saving soil fertility is the important environmental problem of the XXI century. In: Soils and fertility at the turn of the century. II Congress of Belorussian Soil Scientists' Society. Theoretical and practical soil science problems, Minsk, vol 1, pp 74–75 (Russian)

Filip'yev ID, VVGamayunova VV, Baliuk SA (2009) Systems of crop fertilization. In: SA irrigated land of Ukraine. Agricultural Science Publishers, Kyiv, pp 279–299 (Ukrainian)

Gamajunova VV (2004) Current status, problems and prospects of fertilizer usage in irrigated agriculture of the Southern Zone of Ukraine. In: Gamajunova VV, Filip'yev ID, Sidyakina AV (eds) Soil science, agricultural chemistry, agriculture, forestry, no. 1. Kharkiv National University Bulletin, Kharkiv, pp 181–186

Gamajunova VV (2006) Phytosanitary monitoring fertility of irrigated soils. Training guide for agrochemical survey of agricultural land. Kherson (Ukrainian)

Gamajunova VV (2014) Change of soil fertility in the Southern Steppe of Ukraine under the influence of fertilizers and approaches to their effective use in modern agriculture. In: Agricultural Chemistry and Soil Science—special issue on the IX Congress of the Ukrainian Society of Soil Scientists and Agro-chemists, Plenary Lectures. Kharkiv, vol 1, pp 38–47 (Ukrainian)

Karpova EA (1991) Arsenic in soils and plants. Chem Selsk 4:30–34 (Ukrainian)

Krutya VM, Tarariko OG (2000) Agriculture in low moisture (scientific and practical conclusions). Agricultural Science Publishers, Kyiv (Ukrainian)