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GREATER SOIL WATER HARVESTING AND CROP YIELDS WITH NO-TILL AND CROP-RESIDUE RETENTION

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Summary. Global heating is already impacting agriculture across the steppes. Increasing temperatures and capricious rainfall are aggravating problems related to soil health, loss of soil fertility, soil erosion and compaction. The industrial model of agricultural intensification has brought no relief: rather, intensive ploughing has decimated soil organic matter and soil structure, cutting infiltration and water retention capacity while encouraging soil erosion and compaction. Sustainability requires a new strategy based on Conservation Agriculture but, because CA has been largely a farmers' movement, systematic research has been lagging. A long-term no-till field experiment on the *Typical Chernozem* of the Bălți Steppe, in Moldova, demonstrates the influence of different rates of crop residues on soil water accumulation and yields of winter barley following corn-for-grain.

Keywords: *Climate change, drought, conservation agriculture, crop residues*

Introduction. Climate change poses immense challenges, not least to the food system. Global heating and associated changes in rainfall patterns may be responsible for agricultural production losses of 65-70 per cent which are not being counteracted by crop breeding or other new technologies [1]. Across the Steppes, meteorological drought – that is, lower than normal precipitation – is occurring more often while extreme factors acting over a few hours to a few days (severe frost, hail, extreme heat and rainfall) can also have a considerable impact on field crops.

Soil quality and health are critical for adapting to climate change and, across the steppes, especially as they determine infiltration capacity and the storage and release of soil water to crops [2]. Soil quality is hard to change but soil health – the ability of living soil to function within the limits of a natural or managed ecosystem, to support plant and animal productivity, to maintain or improve water and air quality, and to ensure the health of plants and animals –

is in the hands of the farmer [3]. Ploughing and application of mineral fertilizers and pesticides have decimated soil biodiversity, soil structure and, in the case of Chernozem, halved the initial stocks of organic matter that maintains life in the soil and resilience against drought and erosion. In 1892, in his book *Our steppes before and now*, Dokuchaev attributed soil degradation and the resulting impact of droughts to the destruction of the natural vegetation and the granular structure of virgin soil while his contemporary and co-worker Izmailsky ascribed drought more to the state of soil surface than lack of rain. In other words, not so much *meteorological drought* as *agricultural drought* [4, 5].

A hundred years on, things have only got worse, so the primary objective in rebuilding agroecosystems should be to improve agrophysical properties that will enable the accumulation and maintenance of water soil water reserves. In the face of the increasing industrialization of agriculture, and from tentative beginnings in the USA in the 1930s, a global farmers' movement has grown to encompass 15 per cent of global cropland under the banner of Conservation Agriculture [6, 7, 8]. The evolving concept integrates zero tillage (direct drilling); continuous soil cover by crops and crop residues, and diverse crop rotation. In concert, these practices protect the soil from sun, rain, wind and to feed the soil biota that maintain essential soil functions. At the same time, the fuel and labour costs of the system are dramatically reduced compared with conventional practice. However, because CA has been essentially a farmers' movement, systematic research has not kept up with the new issues, notably the oft-reported yield dip in the early years of adopting CA and the significance of increased infiltration and soil water accumulation.

A fundamental principle of CA is to keep the soil covered by a protective mulch of crop residues, particularly in the period between harvest and the achievement of full cover by the subsequent crop. This protects the soil from erosion, compaction and weed infestation; it is better able to absorb rainfall and snowmelt; and early research on no-till winter cereals at Selectia Research Institute of Field Crops on the Bălţi Steppe, Republic of Moldova, appeared to overturn conventional wisdom that early-harvested predecessors offer a big yield advantage to the following crop compared with late-harvested predecessors, like corn-for-grain. No-till with crop-residue retention accumulated more water after a late-harvested predecessor than conventionally cultivated crops with early-harvested predecessors [9]. The following research follows up on the questions raised by these results, focussing on water

accumulation, rain-use efficiency and grain yield of direct-drilled winter barley under different rates of ground cover by crop residues.

Materials and methods. The research was undertaken on *Typical chernozem* soil within a long-term field experiment at the Selectia RIFC, focusing on the winter barley crop in a 7-field crop rotation of 3-years lucerne – winter wheat – sugar beet – corn-for-grain – winter barley. Winter barley, variety Scînteia, was direct-drilled into the preceding maize stover on October 11, 2019, using the Moore Unidrill, without chemical control of weeds and pests. Three levels of crop residues were applied against three fertilization backgrounds: unfertilized, fertilized with manure (40t/ha applied before the sugar beet crop) and combined manure and mineral fertilizer (40 t/ha + PK but with half the plot receiving mineral N and half not), all with three replicates (Figure 1). Each plot was 25 m^2.

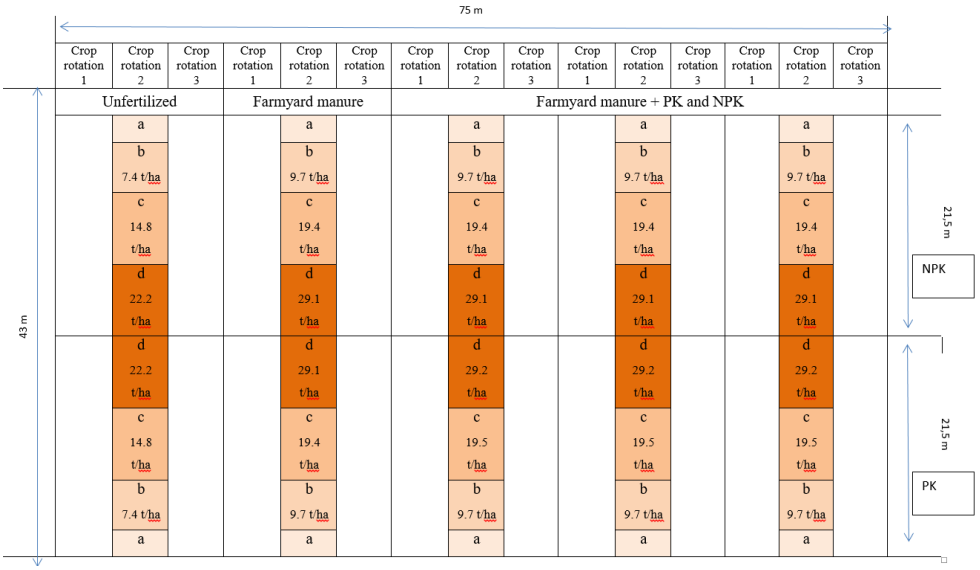


Figure1. Experimental design with different rates of crop residues for winter barley sown after corn for grain, (year 2020) a) without crop residues b) 1 rate of crop residues c) 2 rates of crop residues d) 3 rates of crop residues

Ambient temperature and precipitation were recorded at the Selectia RIFC meteorological station; sampling and determination of nutrient content and soil water was performed by classical methods; crop yields were measured on site by a Wintersteiger Delta (Austria) combined harvester and, subsequently, the quantity of grain from each plot was weighed; statistical analysis applied procedures recommended by Dospehov [10].

Results and discussion. The weather in agricultural year 2019-2020 was extremely dry – most months received well-below-average precipitation (Figure 2); and monthly mean temperatures were consistently above the long-term mean, the only exception being May 2020 – temperatures in the autumn-spring period were much higher than the multiannual average, reaching 6°C above the long-term mean in February (Figure 3). Thus, crops were under stress for almost the whole growing season and winter cereals suffered uneven and delayed emergence: the first winter wheat and winter barley emerged only in January 20-25.

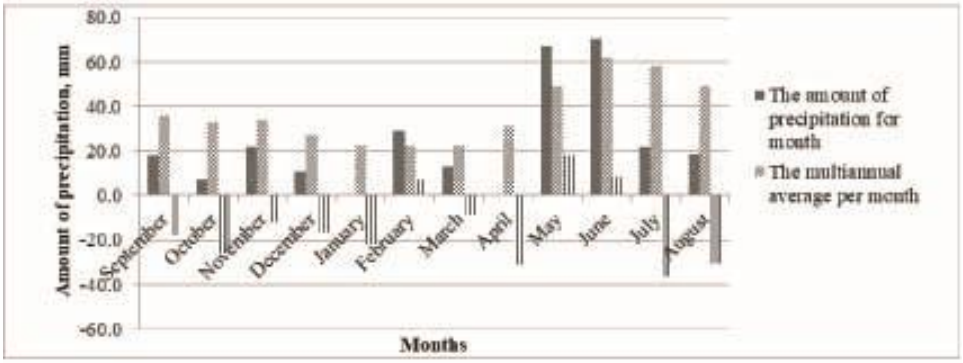


Figure 2. Analysis of rainfall during the agricultural year 2019-2020 in comparison with the multiannual average

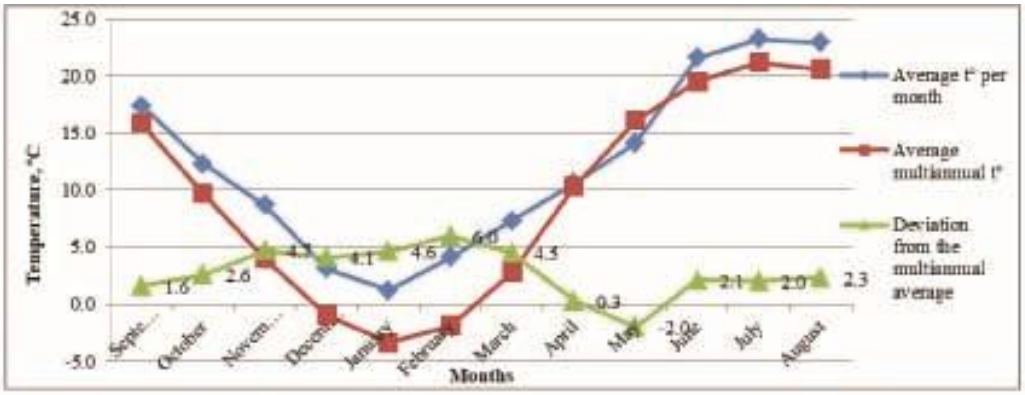


Figure 3. Mean monthly temperature in 2019-20 compared with the multiannual average

In the second decade of April, when the crop was well-established, soil samples were taken for determination of the stocks of soil water and nutrients. It was found that, in unfertilized soils, all rates of crop residues increased the accumulation of soil water, both in the top metre of the soil profile and the second, with no significant difference between the different rates (Table 1).

Table 1. Influence of different rates of crop residues on soil moisture stocks (mm) with different systems of fertilization

System of fertilization	Rates of crop residue	Soil layer, cm		± from the rates of crop residues, soil layer 0-100cm	± from the rates of crop residues, soil layer 0-200cm
		0-100	0-200		
Unfertilized	0	56.2	115.9	-	-
	1	71.2	138.9	+15.0	+23.0
	2	71.2	136.9	+15.0	+21.0
	3	70.9	141.6	+14.7	+25.7
Farmyard manure	0	112.4	230.8	-	-
	1	139.3	256.1	+26.9	+25.3
	2	89.7	176.8	-22.7	-54.0
	3	73.5	154.0	-38.9	-76.8
Farmyard manure + PK	0	74.0	159.6	-	-
	1	79.0	177.5	+5.0	+17.9
	2	94.4	178.3	+20.4	+18.7
	3	84.2	171.8	+10.2	+12.2
Farmyard manure + NPK	0	86.1	180.2	-	-
	1	80.2	175.1	-5.9	-5.1
	2	78.3	165.8	-7.8	-14.4
	3	80.2	168.5	-5.9	-11.7

On plots that had earlier received farmyard manure, a soil water stocks were greater with a single rate of crop residues, but less under the higher rates of crop residues, even compared with the soil without crop residues. Under combined manure and mineral fertilizer, water stocks were greater with a single rate of crop residues, but application of double or triple rates again resulted in lesser stocks of soil water, even relative to the control (without crop residues). With the application of phosphorus and potassium fertilizers in addition to the post-action of farmyard manure, all rates of crop residues increased soil water accumulation, the surplus compared to the control varying between +5.0 and +20.4mm. In contrast, all applications of crop residues on the background with nitrogen fertilizer curtailed soil water accumulation.

After harvest, soil samples were collected for determination the stocks of soil water (Table 2). On the unfertilized plots, stocks of soil water increased in

line with the rates of crop residues. The same regularity is characteristic of the plots receiving farmyard manure but the water stocks were higher than on unfertilized plots. Supplementary application of mineral fertilizers was associated with lesser soil water stocks compared with manure alone; and mineral N fertilizer was associated with significantly less post-harvest soil water.

Table 2. Stocks of soil moisture after harvesting winter barley under different systems of fertilization and applied rates of crop residues

Systems of fertilization	Rates of crop residues	Soil layer, cm		± from the rates of crop residues, soil layer 0-100 cm	± from the rates of crop residues, soil layer 0-200cm
		0-100	0-200		
Unfertilized	0	37.6	103.8	-	-
	1	42.9	124.5	5.3	20.7
	2	49.3	115.7	11.7	11.9
	3	76.9	157.0	39.3	53.2
Farmyard manure	0	55.4	132.9	-	-
	1	60.9	141.7	5.5	8.8
	2	58.3	144.4	2.9	11.5
	3	64.4	155.7	9.0	22.8
Farmyard manure + PK	0	40.0	116.1	-	-
	1	51.3	136.3	11.3	20.2
	2	49.7	122.8	9.7	6.7
	3	51.2	130.2	11.2	14.1
Farmyard manure + NPK	0	39.7	120.3	-	-
	1	44.6	128.1	4.9	7.8
	2	43.4	120.7	3.7	0.4
	3	44.2	136.0	4.5	15.7

In the absence of fertilization, application of crop residues led to a considerable reduction of yields; the greater the application of crop residues, the greater the yield penalty. The best yields were obtained when using mineral fertilizers, including nitrogen fertilizers on the background of post-action manure. Fertilization, particularly with farmyard manure, also increased the water harvest by crop residues so, to obtain the benefits of crop residues, it is

necessary to combine them with a suitable fertilization system, taking into account the C:N ratio.

Regardless of the system of fertilization, there is an opposite process to that in the unfertilized plots: the crop yield is reduced on plots without crop residues, except for the case with P and K mineral fertilizers supplementing the post-action of farmyard manure. The addition of mineral nitrogen fertilizer produced the highest yields based on three rates of crop residues: the average yields from plots with the highest application of crop residues was 3.17t/ha, and the extra yields from the application of the triple rate of crop residues was +1.41t/ha whereas, in the absence of crop residues, additional mineral nitrogen depressed the yield by 1.21t/ha.

Table 3. Grain yields of winter barley depending on the fertilization system and the rates of crop residues, mean of three replicates

Systems of fertilization	Rates of crop residues	Yields, t/ha	Extra yields from fertilization, t/ha	± yields from crop residues, t/ha	± yields from mineral nitrogen fertilizers, t/ha
Unfertilized	0	2.18	-	-	-
	1	1.58	-	-0.60	-
	2	1.29	-	-0.89	-
	3	0.92	-	-1.26	-
Farmyard manure	0	1.98	-0.20	-	-
	1	2.75	+1.17	+0.77	-
	2	2.14	+0.85	+0.16	-
	3	2.36	+1.44	+0.38	-
Farmyard manure + PK	0	2.97	+0.79	-	-
	1	2.29	+0.71	-0.68	-
	2	2.62	+1.33	-0.35	-
	3	2.28	+1.36	-0.69	-
Farmyard manure + NPK	0	1.76	-0.42	-	-1.21
	1	2.18	+0.60	+0.42	-0.11
	2	2.80	+1.51	+1.04	+0.18
	3	3.17	+2.25	+1.41	+0.89

DL_{05} = 0.19 t/ha, $P_{\%}$ = 2.6

These results chime with the depression of yields common in the early years of adoption of no-till. The simultaneous diminution of mineralization of soil organic matter and the accumulation of crop residues on the soil surface, because of cessation of ploughing, leads to N starvation because of the drawdown of nitrogen by microorganisms breaking down the enhanced supply of organic matter. In the Selectia field experiment, the application of nitrogen fertilizers counteracts nitrogen starvation so the greater the addition of crop residues, the greater the succeeding cereal yield whereas application of mineral nitrogen is not effective without application of crop residues. This is in line with the experience of no-till farmers who find that nitrogen application rates on non-leguminous crops need to be increased by up to 25-30 per cent in the early years of adoption, especially in the first year, but this situation normalizes after 2-3 years.

Water consumption per tonne of grain produced varied significantly (Figure 3)

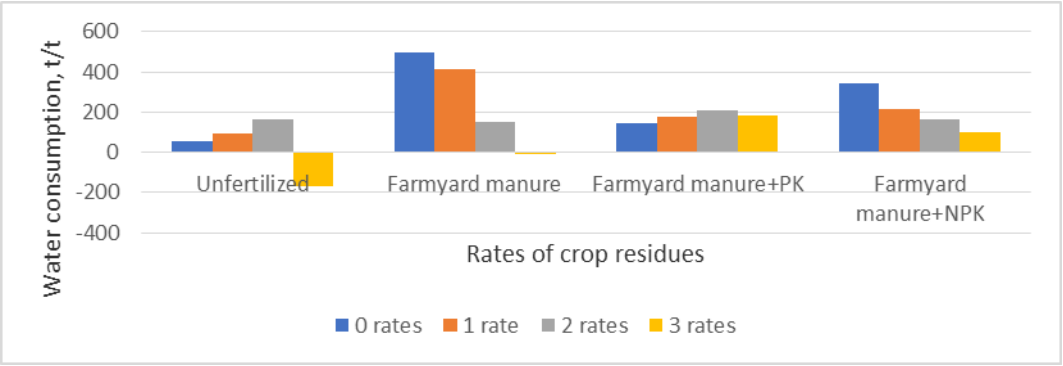


Figure 3. Water use efficiency for the formation of 1 tonne of winter barley, under the influence of fertilization and rates of crop residues, t/t

Water use efficiency is the amount of soil moisture per one ton of grain production.

Water use efficiency is a difference between stocks of soil moisture from spring (on the beginning of plant vegetation) and after harvesting winter barley. Obtained difference was converted from mm to tons and after that was divided on yield of winter barley.

The lowest water use efficiency has been observed on the plots without fertilization, where the production level is considerably lower. Higher water consumption was observed on fertilized plots, particularly plots not receiving a

surface mulch of crop residues. For plots receiving dressings of crop residues, a reduction of water use efficiency was observed simultaneously with the increase of the amount of crop residues left on the soil surface as mulch.

Conclusions:

1. The most beneficial influence the first of crop residues has been noticed for farmyard manure background.
2. Application of NPK on the background of farmyard manure is reducing the stocks of soil moisture in the spring. The same tendency remain valuable for the period after harvesting winter barley.
3. The greatest extra yield from the application of crop residues was obtained on the background of farmyard manure together with mineral fertilizers (NPK).
4. Water use efficiency was the highest on the background of separate application of farmyard manure.
5. Lack of nitrogen from mineral fertilizers is contributing to yield reduction of winter barley.

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