Sustainable and resilient management of Chernozem Soils in Moldova

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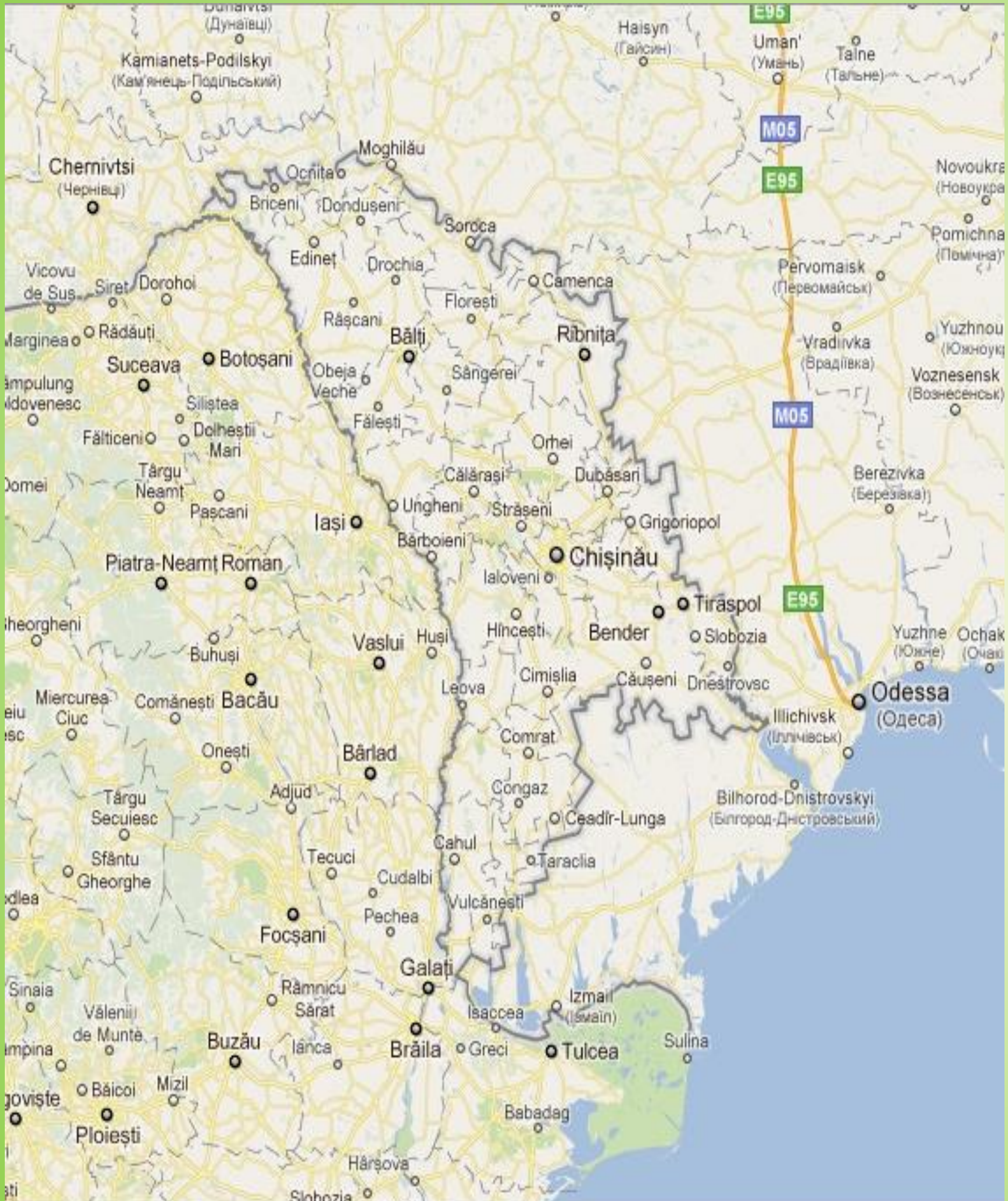
- **Agronomist**
- **Native language – Moldavian (Romanian)**

Studies

- **Moscow Agricultural Academy by name of K.A. Timiriazev (1978), Faculty of Agronomy (Russia)**
- **PhD in agriculture (soil organic matter transformation on arable non-Chernozem soils from Moscow region (1982)**
- **Doctor habilitate of agricultural sciences (crop rotations and soil organic matter on Chernozem of Moldova) defended at Moscow Agricultural Academy by name of K.A. Timiriazev**

Work experience:

- Since 1982 until now working at Selectia Research Institute of Field Crops (SRIFC), Balti, Republic of Moldova
    - Senior research worker (1983-1984)
    - Scientific secretary of the SRIFC (1985-1990)
    - Research director (1993-1999)
    - General director of SRIFC (1999-2009)
    - Head of the Department of Sustainable Farming Systems at SRIFC (since 1990 – until now)
- Chief of the Chair of Natural Sciences and Agroecology at Alecu Russo Balti State University since 2003
- Honorable member of Romanian Academy of Agricultural Sciences, Distinguished scientist of the Republic of Moldova; expert at National Council for the Attestation and Accreditation; expert at the European Commission for Horizon 2020 etc



Republic of Moldova (former Bessarabia) is situated in south – east of Europe and north – east of Balcanians.

The neighbors from west are Romania and from north-east-south are Ukraine.

Surface: 33834,5 km^2

Population: 3572,7 thousands

The highest natural richness of Moldova are fertile soils of the best quality. This was proved for the first time at the exhibitions in Paris (1889, 1900) and been recognized as the “king of all soils in all over the world”.

Soil samples have been taken nearby with Balti, which is located in the northern part of Moldova by Vasile Dokuceaev, the famous Russian scientist who was visiting these places in XIX century and who was presented them for the first time to the scientific community.

SOIL PROFILE FOR TYPICAL THICK CHERNOZEM (HAPLIC CHERNOZEM) UNDER STEPPE VEGETATION

DESCRIPTION: Thick (89 cm) black, humus-rich topsoil with granular structure, characteristic of chernozem, without free carbonates but with deep shrinkage cracks in mid-summer; overlying a strongly mixed layer with warm channels and conspicuous crotovinas infilled with topsoil and subsoil materials and carbonate pseudomycelia, extending to 130 cm; on weathered loess with roots and secondary carbonates extending to 250-270 cm.

Agriculture in all over the world, including in the Republic of Moldova, is facing many challenges at the moment and, especially, for the future:

- **Limited natural resources, including nonrenewable sources of energy (oil, natural gasses, coal) with regularly increased prices on them**
- **Worsening of economic conditions for farmers activities because of unfair increased prices for industrial inputs and agricultural products**
- **Providing food security at the local, regional and global levels in the conditions of higher density of population and climate changes**
- **Biodiversity losses including genetic losses both on the surface of the soil and, especially, in the soil**
- **Soil degradation and danger of ground waters and food pollution on the whole food chain in the conditions of the globalization of economy**
- **Increased negative consequences of the global warming with more frequent manifestation of droughts (heats) and other natural calamities**
- **Rural community disintegration**
- **Increased expenses for public health (nontransmisible diseases)**

Fig. 1 Yields of winter wheat in the Republic of Moldova, average for 1962-2015(t/ha)

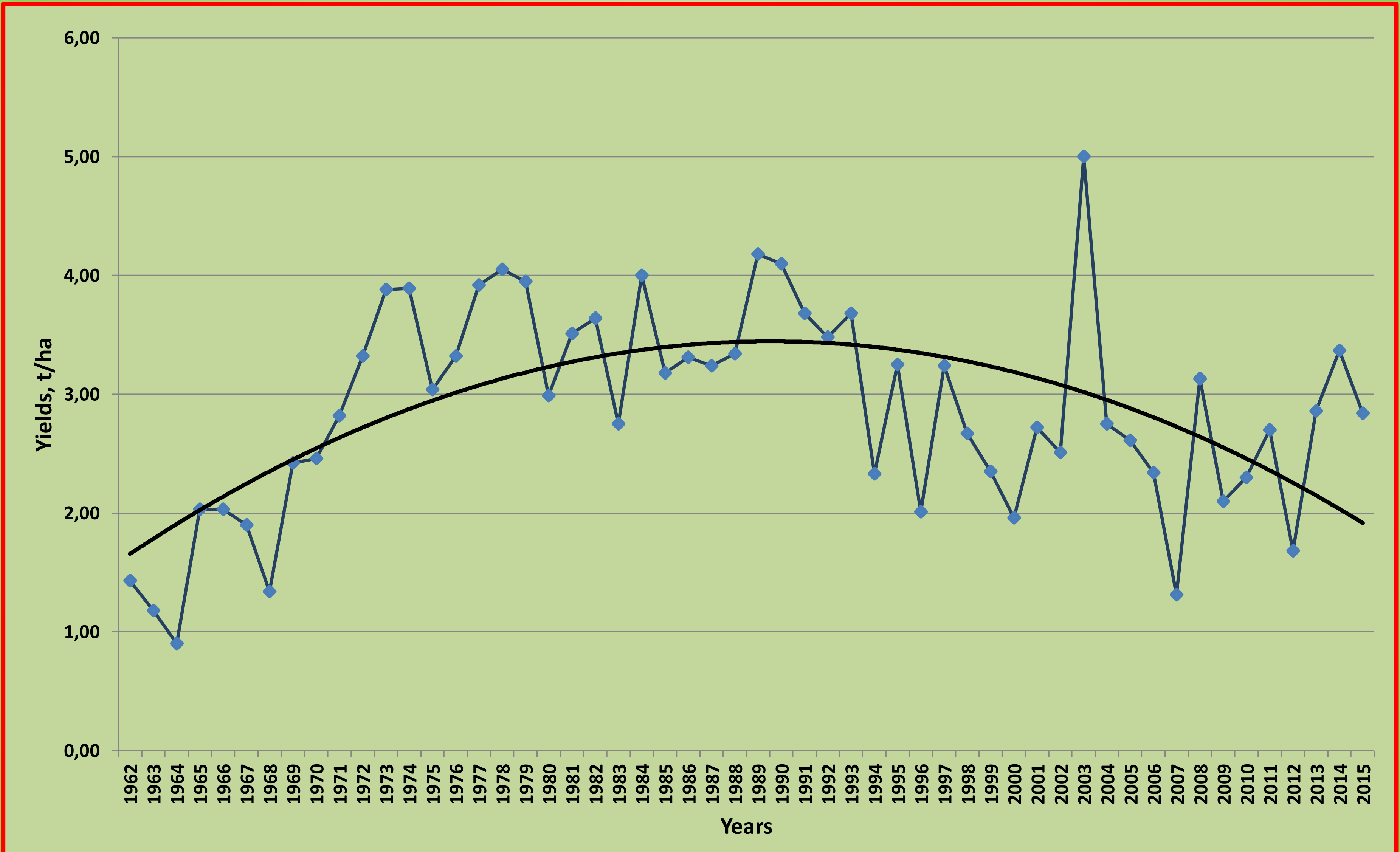
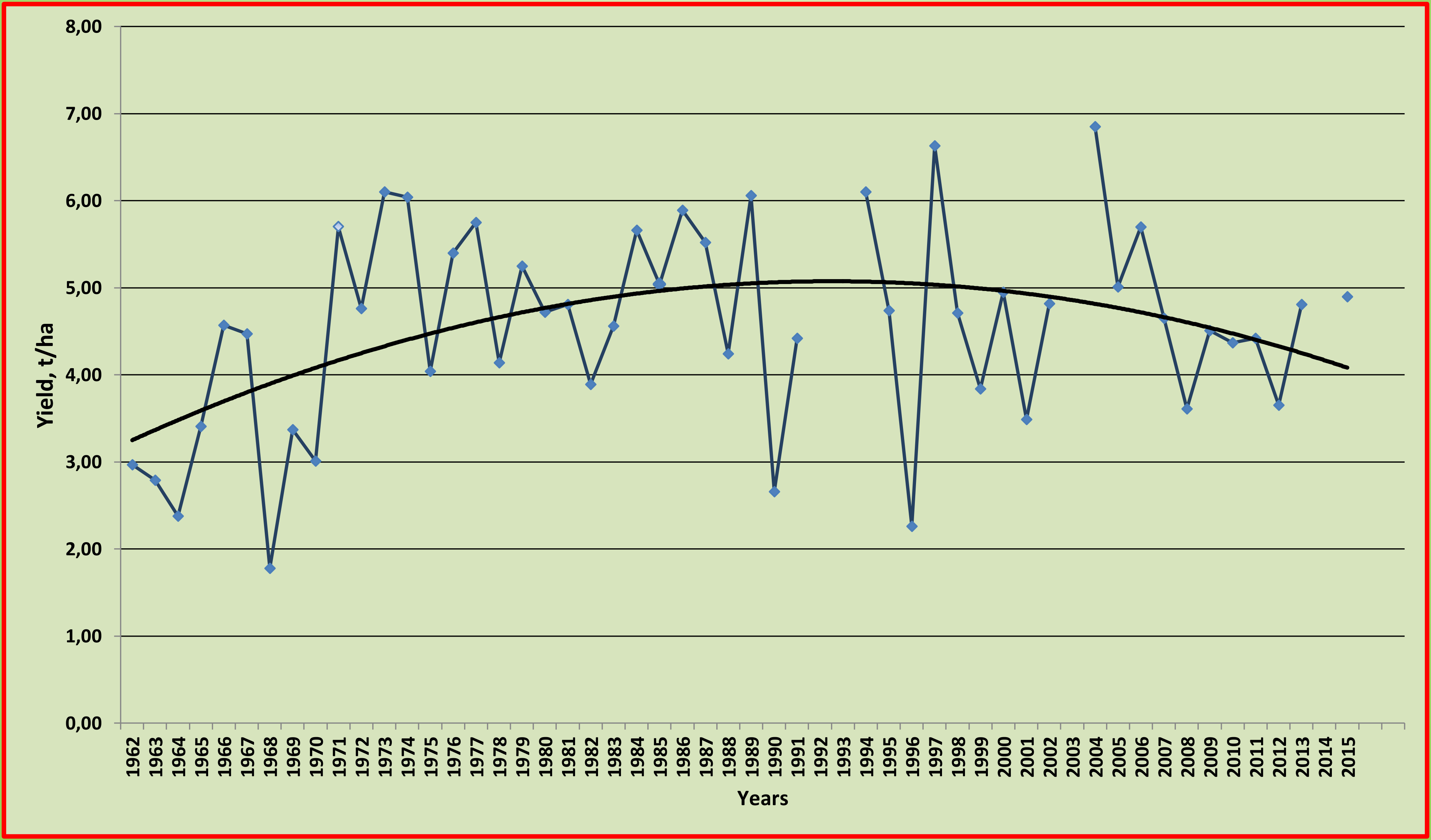


Fig. 2 Yields of winter wheat(t/ha) in the long-term field experiment at Selectia Research Institute of Filed Crops , average for 1962-2015



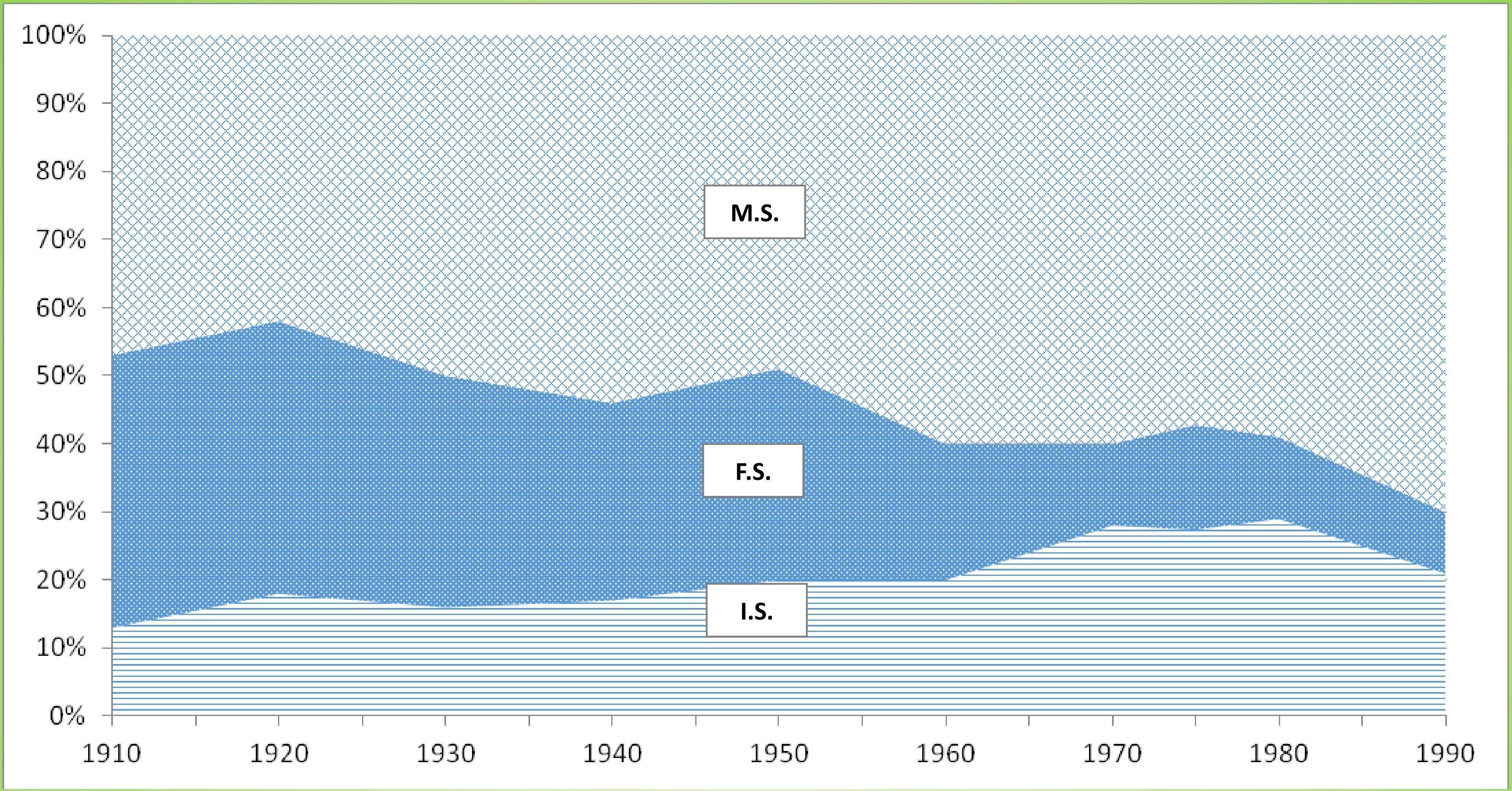


Fig. 4 Distribution of profit between the three sectors of agroindustrial complex (according prof. S. Smith, 1991)

I.S. – input sector

F.S. – farming sector

M.S. – marketing sector (processing, packaging, transportation, marketing)

- **Industrial model of agricultural intensification based on the concept of “Green Revolution” didn’t address many of the above mentioned challenges and consequently didn’t provide a sustainable development. It means agriculture is in crisis**
- **Agriculture is mainly directed towards higher level of yields and profit in the condition of market economy**
- **“Agriculture as usual doesn’t work”**
- **Soil is a living organism and it plays a poly-functional role by providing ecosystem and social services**
- **Agriculture in all over the world requires change of the paradigm of the agricultural intensification – transition from industrial inputs to a better recycling of energy and nutrients in each farm predominantly by using renewable sources of energy of local origin**

Tab.1 “Effect of crop rotation” in the long-term field experiments of Selectia RIFC (Balti, Republic of Moldova), average for 15 years, t/ha and %

Crops	Indices	10 fields crop rotation		7 fields crop rotation		Permanent mono-cropping	
		Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
Winter wheat	t/ha	4,64	5,06	3,96	4,29	1,95	2,84
	± t/ha and %	+2,69/ 137,9%	+2,22/ 78,2%	+2,01/ 103,1%	+1,45/ 51,1%		
Sugar beet	t/ha	33,21	43,00	23,00	38,55	9,05	17,81
	± t/ha and %	+24,16/ 267,0%	+25,19/ 141,4%	+13,95/ 154,1%	+20,74/ 116,5		
Corn for grain	t/ha	5,22	5,67	5,01	5,62	3,75	5,16
	± t/ha and %	+1,47/ 39,2	+0,51/ 9,9%	+1,26/ 33,6%	+0,46/ 8,9%		
Sunflower	t/ha	1,99	2,14	1,40	1,70	1,42	1,56
	± t/ha and %	+0,57/40,1%	+0,58/ 37,2%	-0,02	+0,14/ 9,0%		

Tab.2 The yield of winter wheat after different predecessors in crop rotation and in permanent mono-cropping, average for 1994-2018, in the long-term field experiments at Selectia Research Institute of Field Crops, Republic of Moldova, t/ha and %

Crop rotation, permanent crop	Predecessors of winter wheat	Fertilization		± from fertilization, t/ha and %	Yield reduction relatively to mixture of vetch and oats for green mass	
		Unfertilized	Fertilized		Unfertilized	Fertilized
Crop rotation	mixture of vetch and oats for green mass	4,55	5,14	+0,59/13,0%	-	-
	corn for sillage	3,29	4,69	+1,40/42,6%	-1,26/27,7%	-0,45/8,8%
	corn for grain	2,62	3,71	+1,09/41,6%	-1,93/42,4%	-1,43/27,8%
Permanent crop	winter wheat	1,96	3,02	+1,06/54,1%	-2,59/56,9%	-2,12/41,2%

Tab.3 The share of soil fertility in yield formation for winter wheat (%) in crop rotation and permanent crop, average for 1994-2018, SELECTIA RIFC, Republic of Moldova

Crop rotation, permanent crop	Predecessors of winter wheat	Fertilized plots	Unfertilized plots
Crop rotation	Mixtures of vetch and oats for green mass	87,0	100
	Corn for sillage	57,4	100
	Corn for grain	58,4	100
Permanent crop	Winter wheat	45,9	100

Tab.4 Nitrogen use efficiency (%) by winter wheat sown after different predecessors and in permanent mono-cropping, average for 1994-2018, Selectia RIFC, Republic of Moldova

Crop rotation, mono-cropping	Predecessors	Extra yields from fertilization, t/ha	Nitrogen taken up by extra yields, kg/ha	N applied with mineral fertilizers, kg/ha	N – use efficiency, %	Total N up take on fertilized plots, kg/ha	Share of soil fertility in yield formation, %
Crop rotation	Mixture of oats and vetch for green mass	0,59	19,5	90	21,7	169,6	88,5
	Corn for silage	+1,40	46,2	90	51,3	154,8	70,1
	Corn for grain	+1,09	36,0	90	40,0	122,4	70,6
Mono-cropping	Winter wheat	+1,06	35,0	90	38,9	99,7	64,9

- **The higher is the diversity of crops in the crop rotation the higher is the functionality of soil as a result of a higher biodiversity of organisms for the whole soil food chain**
- **The better are the predecessors for winter wheat the lower are the extra yields from fertilization. Yields reduction from sowing winter wheat after late harvested predecessors is significantly higher than extra yields from fertilization**
- **The share of soil fertility in yield formation of winter wheat is significantly higher after early harvested predecessors than after latter harvested predecessors or permanent cropping**
- **Nitrogen – use efficiency from mineral fertilizers is the lowest when applied after early harvested predecessors and it increases after late harvested predecessors**

Tab. 5 Yields of winter wheat under the influence of different systems of soil tillage and fertilization in crop rotations with and without mixture of legumes and grasses, average for 3 rotations in the poly-factorial experiment at RIFC, Balti, Moldova, t/ha and %

Systems of soil tillage	Crop rotation without perennial crops			Crop rotation with perennial crops		
	Control (without fertilization)	Farmyard manure	Farmyard manure +NPK	Control (without fertilization)	Farmyard manure	Farmyard manure +NPK
Winter wheat						
Moldboard plow	2,85	3,30	4,10	4,40	4,44	4,51
Non-inversion tillage	2,82	3,23	4,16	4,32	4,42	4,55
Difference (± and %)	-0,03/1,1%	-0,07/2,1%	+0,06/1,5%	-0,08/1,8%	-0,02/0,5%	+0,04/0,9%
Corn for grain						
Moldboard plow	4,76	4,99	5,06	5,14	5,14	5,31
Non-inversion tillage	4,74	4,82	4,93	5,10	5,11	5,20
Difference (± and %)	-0,02/0,4%	-0,17/3,4%	-0,13/2,6%	-0,04/0,8%	-0,03/0,6%	-0,11/2,1%

Tab.6 Soil moisture accumulation (mm) under corn for grain during the fall-spring period of time in different crop rotations, permanent cropping of corn for grain and in black fallow, average for 2006-2015, including in drought year of 2015, Selectia Research Institute of Field Crops, Republic of Moldova

Soil layers, cm	Crop rotations			Permanent cropping	
	70% of row crops	60% row crops + 12 t/ha of manure	40% row crops + 30% alfalfa	Corn for grain	Black fallow
Average for 2006-2015					
0-100	61.1/49.6%	77.4/67.8%	76.9/55.1%	53.9/51.0%	28.8/57.6%
0-200	123.2	114.1	139.5	105.6	50.0
In drought year 2015					
0-100	118.5/66.1%	115/73.7	139.9/55.8	66.1/62.5	38.3/79.8
0-200	179.3	156.0	250.5	105.7	48

Tab.7 Crop yields (t/ha) in different crop rotations and in permanent cropping, average for 2000-2015, including in the drought years

Crops	Crop rotations			Permanent cropping
	70% of row crops	60% row crops + 12 t/ha of manure	40% row crops + 30% alfalfa	
Average for 2000-2015				
Winter wheat	4.15	4.57	4.41	2.81
Corn for Grain	5.63	5.84	6.15	5.45
In drought years				
Winter wheat (2012)	3.00	3.65	4.30	2.50
Corn for Grain (2015)	2.92	3.91	4.50	0

Tab. 8 Water-use efficiency by winter wheat after different predecessors and in permanent cropping, Selectia RIFC, means for 1992-2018

<table>
<tr><th rowspan="2">Soil layers, cm</th><th colspan="2">Soil water stock, mm</th><th rowspan="2">Soil water consumption, mm</th><th rowspan="2">Water consumption from 0-100 cm versus 0-200 cm, %</th><th rowspan="2">Yield, t/ha</th><th rowspan="2">Soil water consumption, tonnes per tonne grain</th></tr>
<tr><th>Spring</th><th>After harvest</th></tr>
<tr><td colspan="7">Winter wheat after Lucerne in 3rd year after 1st cut</td></tr>
<tr><td>0-100</td><td>176.6</td><td>82.8</td><td>93.8</td><td rowspan="2">52.6</td><td rowspan="2">5.13</td><td rowspan="2">374.8</td></tr>
<tr><td>0-200</td><td>352.1</td><td>173.7</td><td>178.4</td></tr>
<tr><td colspan="7">Winter wheat after corn for grain</td></tr>
<tr><td>0-100</td><td>184.7</td><td>79.5</td><td>105.2</td><td rowspan="2">70.8</td><td rowspan="2">3.71</td><td rowspan="2">400.3</td></tr>
<tr><td>0-200</td><td>322.8</td><td>174.3</td><td>148.5</td></tr>
<tr><td colspan="7">Permanent cropping of winter wheat</td></tr>
<tr><td>0-100</td><td>179.4</td><td>91.0</td><td>88.4</td><td rowspan="2">60.0</td><td rowspan="2">3.02</td><td rowspan="2">488.1</td></tr>
<tr><td>0-200</td><td>370.0</td><td>222.6</td><td>147.4</td></tr>
</table>

- By including perennial leguminous crops (alfalfa) in the crop rotation soil quality and yields of winter wheat and corn for grain are increasing, especially in drought conditions, relatively to crop rotations without perennial legumes and permanent mono-cropping
- Accumulation of soil moisture under corn for grain during fall-spring period of time is higher in crop rotation with perennial legumes (alfalfa), especially in drought conditions
- Carbon sequestration is higher in deeper soil layers for crop rotations with lucerne
- Black fallow is less efficient in accumulation of soil moisture relatively to monoculture of corn for grain and especially, with crop rotation
- In crop rotations with the mixture of legumes and grasses the yields of winter wheat and corn for grain are similar irrespective of applied system of fertilization and soil tillage

Tab. 9 Changes in the stocks of soil organic carbon during 1992-2015 in crop rotation with and without lucerne on the Typical Chernozem of the Balti Steppe, t C/ha (mean of 3 replicates)

Soil layers, cm	Crop rotation with lucerne				Crop rotation without lucerne			
	1992	2015	±	%	1992	2015	±	%
0-20	71.0	59.0	-12.0	17.3	66.7	52.6	-14.1	-21.1
20-40	69.6	63.6	-6.0	8.6	62.9	56.4	-6.5	-10.3
40-60	56.2	61.6	+5.4	9.6	51.5	52.5	+1.0	1.9
60-80	37.2	52.9	+15.7	42.2	31.1	38.1	+7.0	22.5
80-100	37.0	43.1	+6.1	16.5	19.3	27.7	+8.4	43.5
0-100			+9.2				-4.2	

Tab. 10 The content of labile fraction of soil carbon (by S. Cambardella) under different systems of soil tillage and fertilization in crop rotations with and without the mixture of perennial legumes and grasses, long-term field polyfactorial experiment on Typical Chernozem of the Balti steppe, Republic of Moldova, 2016

Systems of soil tillage	Soil layers (cm)	Control (without fertilizers)				Farmyard manure + NPK			
		Crop rotation without mixture of perennial legumes and grasses		Crop rotation with mixture of perennial legumes and grasses		Crop rotation without mixture of perennial legumes and grasses		Crop rotation with mixture of perennial legumes and grasses	
		g/100g	%	g/100g	%	g/100g	%	g/100g	%
Moldboard plow	0-20	122,0	4,9	124,0	5,1	203,0	7,8	248,0	9,7
	20-40	88,0	3,6	92,0	3,9	106,0	4,1	148,0	5,9
Non-inversion tillage	0-20	119,0	5,0	162,0	6,3	276,0	10,0	358,0	12,8
	0-40	74,0	3,2	109,0	4,4	138,0	5,0	214,0	7,9

Tab.11 Stocks and losses of soil organic matter (on carbon) for Typical Chernozem from Balti Steppe, Republic of Moldova, soil layer 0-100 cm

Soil layers, cm		Meadow (native grassland field)		Stocks and losses relative to native grassland field								
				Crop rotation with alfalfa (30%)+40% row crops			Crop rotation without alfalfa + 60 % of row crops (12 t/ha manure)			55-yrs continuous black fallow		
		t/ha	%	t/ha	±	%	t/ha	±	%	t/ha	±	%
0-100		342,3	100	273,7	-68,6	20,0	281,7	-60,6	17,7	222,3	-120,0	35,1
Including	0-60	225,3	65,8	182,2	-158,1	46,2	200,8	-141,5	41,3	161,5	-180,8	52.8
	% relative to 0-100 cm	65,8		67,3			71,3			72,6		

Tab. 12 Stocks and losses of soil organic carbon since 1970 under a 6 years crop rotation with 50% row crops and different systems of fertilization

Soil layers, cm	Meadow		Unfertilized since 1970			Fertilized with NPK (130 kg a.i./ha)			Fertilized with 15 t/ha farmyard manure +NPK 130 kg a.i./ha		
	t/ha	%	t/ha	±	%	t/ha	±	%	t/ha	±	%
0-100	342.3	100	176.5	-165.8	48	150.2	-192.1	56	200.4	-141.9	41
Including 0-60 cm	225.3		159.9	- 65.4	29	136.7	- 88.6	39	176.2	- 49.1	22
% of 0-100 cm	66		91			91			88		

Tab.13 Potential for carbon sequestration on arable soils in the Chernozem regions of Russia, Ukraine and Moldova

States	Total arable areas under Chernozems, mln ha	Losses of SOC relative to grassland, t C/ha	Emission of CO_2, t CO_2/ha (x3,7)	Total CO2 emissions, mln tons of CO_2 for arable land
Russia	145,4	60,0	222	32278,8
Ukraine	27,8	60,0	222	6171,6
Republic of Moldova	1,4	60,0	222	318,8
Total	174,6			38769,2

- **The size of the labile fraction of soil organic matter is higher on fertilized plots with farmyard manure + NPK, especially in crop rotation with the mixture of perennial legumes and grasses on non-inversion system of soil tillage**
- **On soils with good quality (health) mechanical tillage can be replaced by biological tillage**
- **Agroecological approach to agricultural intensification supposes a holistic (systemic) approach to agricultural intensification in order to conserve local resources by managing relatively small-scale agriculture**
- **A new regenerative farming system allows to make agriculture truly sustainable by increasing the economic competitiveness through reducing reliance on agrochemicals and fuel and by reducing the negative environment and social impact of farming systems, including higher resilience to global warming**

Conclusions:

1. In order to answer to many challenges faced by modern agriculture a new agro-ecological paradigm (concept) for sustainable and resilient agriculture is required
2. Building healthy Chernozem soils in the frame of crop rotations with a higher diversity of crops allows to reduce utilization of industrial inputs (mineral fertilizers, especially nitrogen; pesticides for weed, pest and disease control; to replace inversive by non-inversive soil tillage or No-till etc.
3. Chernozems have a high potential for carbon sequestration and consequently for the reduction of global warming and increasing food security at the local, regional and global levels

Thanks for your attention!