Agroecological approach to agricultural intensification

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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)

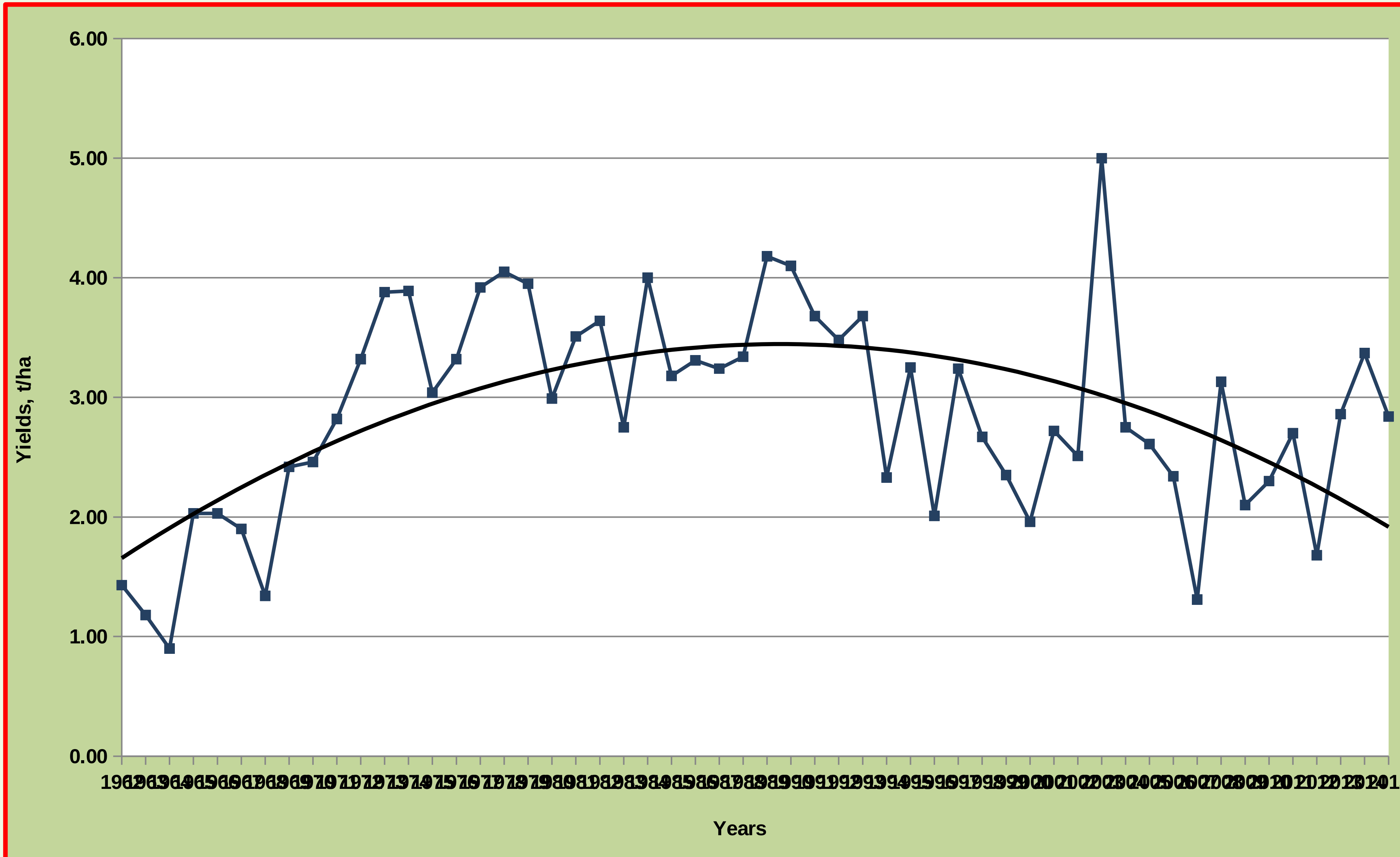
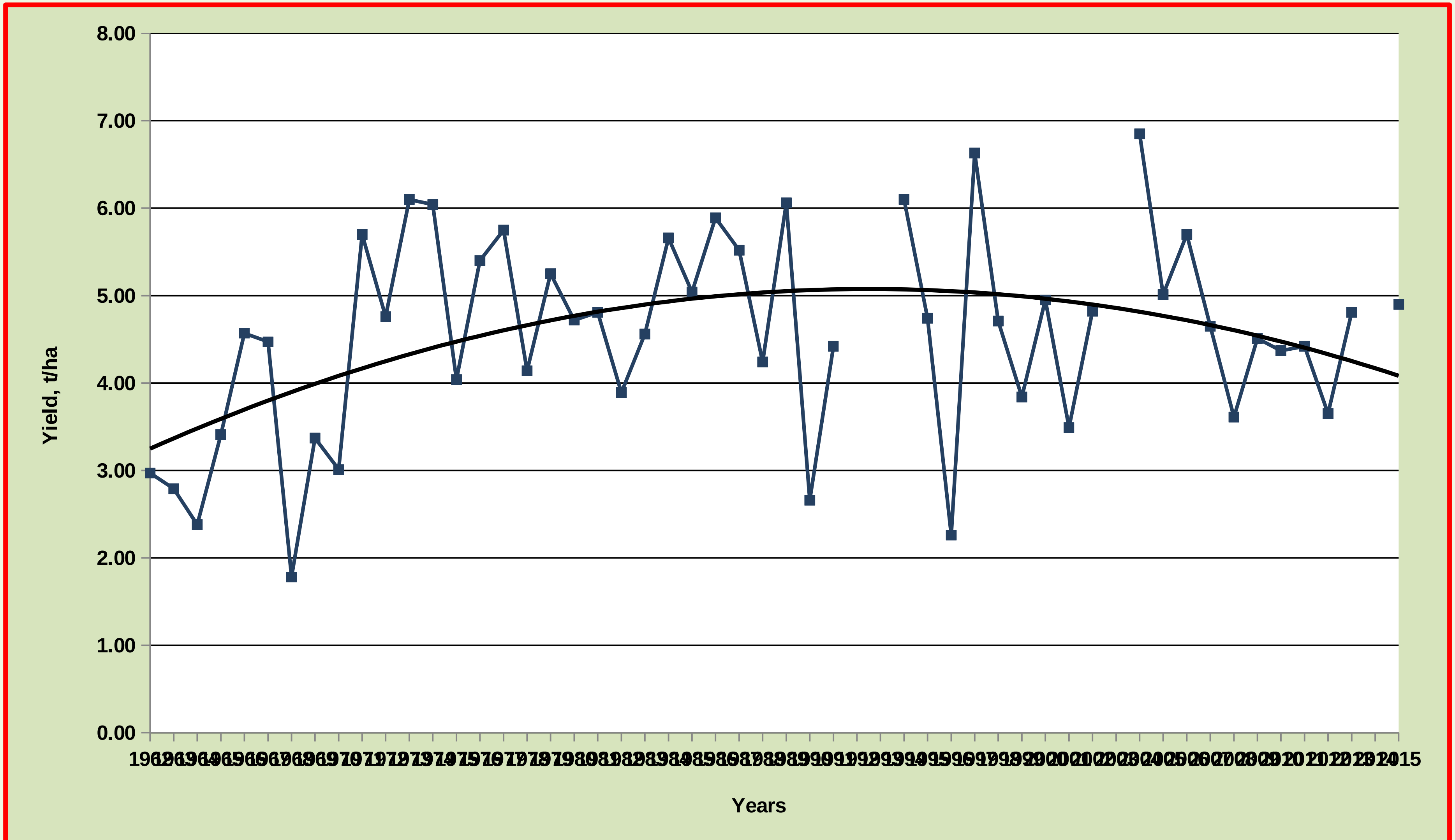
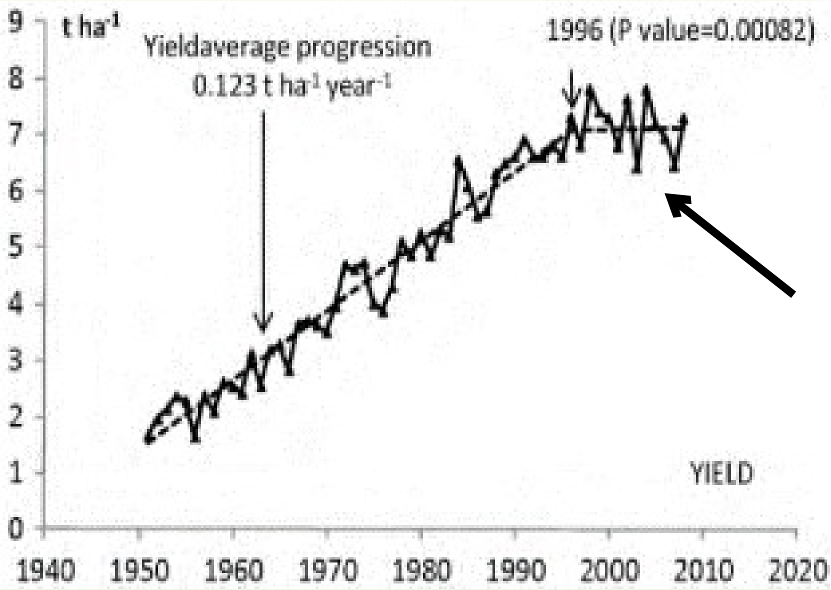


Fig. 2 Yields of winter wheat (t/ha) in the long-term field experiment at Selectia Research Institute of Filed Crops , average for 1962-2015



Stagnating Yields (yield gap)

Fig. 3 Rising-plateau regression analysis of wheat yields throughout European countries



Country	Year of stagnation
Denmark	1995 (**)
France	1996 (**)
Germany	1999
Italy	1994
Netherlands	1993 (**)
Spain	1989
Switzerland	1990 (**)
United Kingdom	1996 (**)

(Brisson et al. 2010)

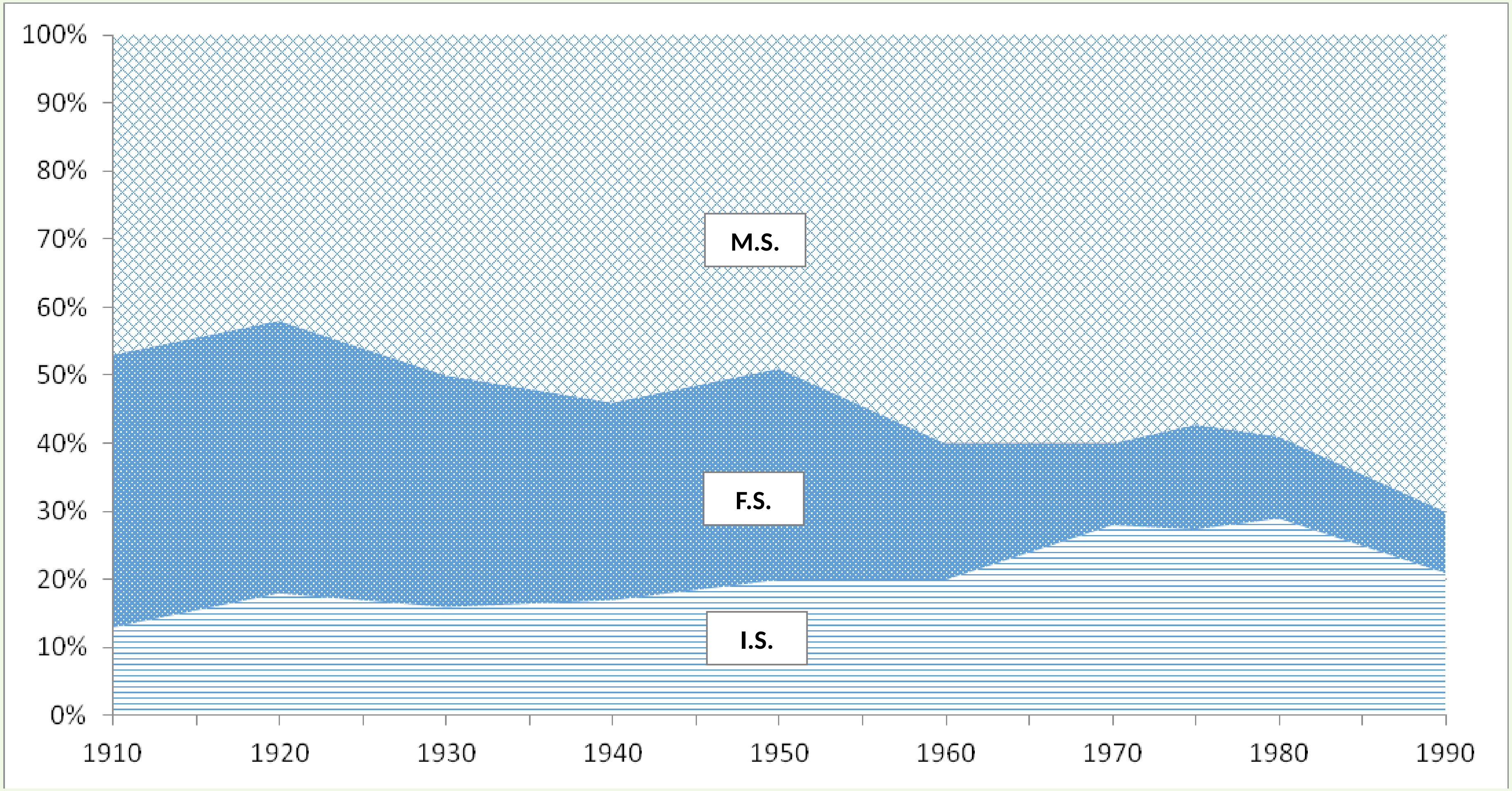


Fig. 4. Distribution of profit between the three sectors of agroindustrial complex (according prof. S. Smith, 1991)

I.S. – input sector

F.S. – farming sector

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

Tab. 1 The required of extra yields to pay off applied rates of mineral fertilizers, Selectia Research Institute of Filed Crops, Republic of Moldova

Crops	Rates of mineral fertilizers, kg a.i./ha	Extra yields obtained in average for 2011-2016, t/ha	Required level of extra yields to pay off fertilizers, t/ha
Winter Wheat	NPK 75	0.64	0.91
	NPK 130	0.49	1.70
	NPK 175	0.69	1.82
Sugar Beet	NPK 75	3.75	3.0
	NPK 130	4.80	5.7
	NPK 175	5.45	6.6
Corn for Grain	NPK 75	0.91	1.14
	NPK 130	0.82	1.78
	NPK 175	0.26	2.56
Sunflower	NPK 75	0.27	0.40
	NPK 130	0.33	0.70
	NPK 175	0.33	0.75

- **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.2 "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. 3 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

Tab. 4 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. 5 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

- **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. 6 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. 7 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. 8 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. 9 Water-use efficiency by winter wheat after different predecessors and in permanent cropping, Selectia RIFC, means for 1992-2018

Soil layers, cm	Soil water stock, mm		Soil water consumption, mm	Water consumption from 0-100 cm versus 0-200 cm, %	Yield, t/ha	Soil water consumption, tonnes per tonne grain
	Spring	After harvest				
Winter wheat after Lucerne in 3rd year after 1st cut						
0-100	176.6	82.8	93.8	52.6	5.13	347.8
0-200	352.1	173.7	178.4			
Winter wheat after corn for grain						
0-100	184.7	79.5	105.2	70.8	3.71	400.3
0-200	322.8	174.3	148.5			
Permanent cropping of winter wheat						
0-100	179.4	91.0	88.4	60.0	3.02	488.1
0-200	370.0	222.6	147.4			

- **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. 10 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		

- **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**

Tab. 11 Structural and functional differences between natural ecosystems and agroecosystems (Odum, 1969 and Gliessman, 2000)

Indicators	Natural ecosystems	Agroecosystems
Net productivity	Medium	High
Trophic interaction	Complex	Simple, linear
Species diversity	High	Low
Genetic diversity	High	Low
Nutrient and energy cycles	Closed	Open
Stability (resilience)	High	Low
Human control	Independent	Dependent
Temporal performance	Long	Short
Habitat heterogeneity (ecological infrastructure)	Complex	Simple

Soil quality (soil health) is crucial in the transition to a more sustainable agriculture

- **Soil organic matter (humus) is an integral index of soil fertility (soil quality, soil health)**
- **Changes in the soil structure due to compaction by heavy farm equipment suppress root development, thus reducing the quantity of soil nutrients and water that can be accessed by crops**
- **A decline in soil organic matter following intensive tillage can reduce the water-holding capacity of a soil, making the crop more susceptible to water deficits and drought during the growing season**
- **A soil with good physical, chemical and biological, proprieties is able to produce higher crop yields, can generate more income than a poor – quality soil**

Physical, chemical and biological soil indicators for assessing soil quality (John Doran, 1996):

A. **Physical:**
   - Texture
   - Top soil depth
   - Water infiltration rate
   - Bulk density
   - Water – holding capacity

B. **Chemical:**
   - Soil organic matter
   - Total nitrogen
   - pH
   - Electrical conductivity
   - Extractable nutrients (N, P, K)

C. **Biological**
   - Microbial biomass carbon
   - Microbial biomass nitrogen
   - Potentially mineralizable nitrogen
   - Soil respiration Earthworms

A good quality soil can provide besides a relevant crop production, a better ecosystem services:

- **filtering and purifying water before it is released to waterways**
- **inorganic and organic pollutants can be absorbed and some can be degraded**
- **buffer for climate changes by promoting the growth of plants that sequester CO_2 from the atmosphere and contributing to the humification and physical protection of carbon from plants and other organic residues**
- **healthy soil provides health for the whole chain: crops – animals – people**
- **changing the habits to eat will stimulate transition to a more sustainable agriculture.**

Tab. 12 The effect of crop rotation and fertilization for winter barley sown by using No-till after corn for grain, average for 2015-2018 years, long-term field experiment at Selectia Research Institute of Field Crops, Balti, Republic of Moldova

Crop rotation		Permanent cropping		Extra yields from crop rotation		Extra yields from fertilization	
unfert.	fertil.	unfert.	fertil.	unfert.	fertil.	in crop rotation	in permanent cropping
2.39	5.19	1.56	4.03	+083/53.2%	+1.16/28.8%	+2.8/117.2%	+2.47/158.3%

1. Winter barley is less receptive to crop rotation than winter wheat, but more influenced by the fertilization system
2. Application of composted farmyard manure together with mineral fertilizers in crop rotation doesn’t allow to distinguish their separate action

Tab. 13 Yields of No-till winter barley (sown after corn for grain) in crop rotation with and without mixture of alfalfa and reigras for green mass on different systems of fertilization, average for 2015-2018, t/ha

Fertilization systems in crop rotation	Crop rotation with the mixture of alfalfa and reigras for green mass		Crop rotation without mixture of alfalfa and reigras for green mass	
	t/ha	± and %	t/ha	± and %
Without fertilization	2.49	-	2.72	-
Farmyard manure	4.44	+1.95/78.3	4.71	+1.99/73.2
Farmyard manure + PK	4.67	+2.18/87.6	4.72	+2.00/73.5
Farmyard manure + NPK	4.62	+2.13/85.5	4.86	+2.14/78.7

DL_{05} = 0.23 t/ha

- **Application of composted farmyard manure in crop rotation with and without mixture of perennial legumes and grasses is increasing significantly the yields of No-till winter barley (1.95 t/ha up to 2.18 t/ha or on 78.3% up to 87.6%)**
- **Supplementary application of mineral fertilizers to composted farmyard manure didn’t increase significantly yields of No-till winter barley**
- **Application of composted farmyard manure in the crop rotation with the mixture of perennial legumes and grasses allows to improve soil fertility and maintain high level of yields without supplementary application of mineral fertilizers**

Tab. 14 Yields and soil moisture accumulation during the fall-winter-spring periods of time for No-till winter barley sown after peas for grain (crop rotation N 2) and corn for grain (crop rotations N4 and N5), t/ha, average for 2015-2018 years, Selectia RIFC, Balti, Republic of Moldova

Crop rotations	Predecessors	Yields, t/ha (average for 2015-2018)	Yields, t/ha (average for 2015-2016)	Soil moisture accumulation during fall-winter-spring periods of time, average for 2015-2016, mm	
				0-100 cm	0-200 cm
N2	Peas for grain	4.89	4.50	81.8	109.6
N4	Corn for grain	5.12	4.78	166.9	169.1
N5	Corn for grain	4.97	4.61	127.1	192.0
	DL =	0.19	0.17		

- **Yields No-till winter barley after peas for grain is equal to yields obtained after corn for grain, thanks to a higher accumulation of soil moisture during fall-winter-spring periods of time after harvesting corn for grain relatively to peas for grain**
- **Accumulation of soil moisture is higher in deeper soil layer for No-till winter barley sown after corn for grain in crop rotation with perennial legumes, which is increasing resilience to drought**

Conclusions

1. **Conservation agricultural system requires a holistic approach to farm management through respecting crop rotation with higher diversity of main and successive (cover) crops including mixture of perennial legumes and grasses**

2. **Integration of crop and animal husbandries allows to improve soil, fertility thus reducing the application of industrial inputs (mineral fertilizers, pesticides)**

3. **No-till in crop rotation with perennial legumes and grasses is able to improve the quality of predecessors and to increase resilience to drought thanks a higher capacity to accumulate soil moisture during fall-winter-spring periods of time, especially in deeper soil layers**

Thank you for your attention!