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Cost-effective reducing the environmental impact of wheat production in Siberia

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Abstract. The effects of previous crop, fertilizers and pesticides on the wheat yield and the cost efficiency of wheat production in Siberia were studied in two-year field experiment. It was found that the yield mostly depends on the previous crop and pesticides, whereas the fertilizer demonstrated relatively slight effect in the year favourable for wheat growth and no effect in the year unfavourable for wheat growth. Cost-effectiveness analysis showed that the most effective way to reduce the environmental impact of wheat production in Siberia is the use of fallow in crop rotation scheme. Usage of fallow without chemical fertilisers provides higher yield than variants with fertilisers and pesticides where wheat was used as a previous crop. Cost efficiency of variant with fallow was 20.8% what is comparable with cost efficiency of the most cost effective variants (fallow as a as a previous crop + pesticides with cost efficiency of 36.6% and wheat as a previous crop + fertilizers with cost efficiency of 30.4%).

1. Introduction

Pesticides and chemical fertilizers pose serious threats to the environment, cause the degradation of the soil and, in case of pesticides, are dangerous for human health [1], [2], [3], [4]. In order to minimize the environmental and health risks in Europe and other developed countries farmers are encouraged to reduce their use [5].

From other hand there is a sustained opinion that only usage of pesticides and fertilizers can provide high and stable yield. Until now, insufficient attention has been paid to effect of crop rotation as possible way to achieve cost-effective reducing the environmental impact of agriculture.

In the present research the effects of previous crop, fertilizers and pesticides on the wheat yield and the cost efficiency of wheat production in Siberia were studied.

2. Methods and results

The yield of the one of the most popular in Siberia spring wheat (*Triricum aestivum* L.) cultivar Novosibirskaya-31 was studied in the field experiments according to the scheme presented in Table 1. Cost-effectiveness was calculated as a difference between revenue and expenses divided by expenses for one ton of wheat produced per year. Factorial ANOVA and cost-effectiveness analysis were based on two years' data: the year 2016 and the year 2017.

Statistical analysis was performed with Stat Soft STATISTICA Version 6.0 statistic software package.

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The year 2016 was favorable for wheat grows whereas the year 2017 was unfavorable because of severe drought at the beginning of vegetation. This drought resulted in statistically significant ($p<0.001$) yield decrease in 2017 in comparison with 2016. Average yield in 2017 was 1.41 metric tons per hectare in contrast with 3.84 metric tons per hectare in 2016.

Table 1. Design of experiment.

Code	Previous crop	Fertilizers	Pesticides
Wheat	Wheat	No	No
Wheat+Pesticides	Wheat	No	Yes
Wheat+Fertilizers	Wheat	Yes	No
Wheat+Fertilizers+Pesticides	Wheat	Yes	Yes
Fallow	Fallow	No	No
Fallow+Pesticides	Fallow	No	Yes
Fallow+Fertilizers	Fallow	Yes	No
Fallow+Fertilizers+Pesticides	Fallow	Yes	Yes

A strong decrease of yield was observed in all the variants of the experiment (Figure 1). In general, the value of yield decrease was similar for different variants of the experiment, what resulted in high ($r= 0.790$) and statistically significant ($p<0.05$) correlation between yield per variant in 2016 and 2017.

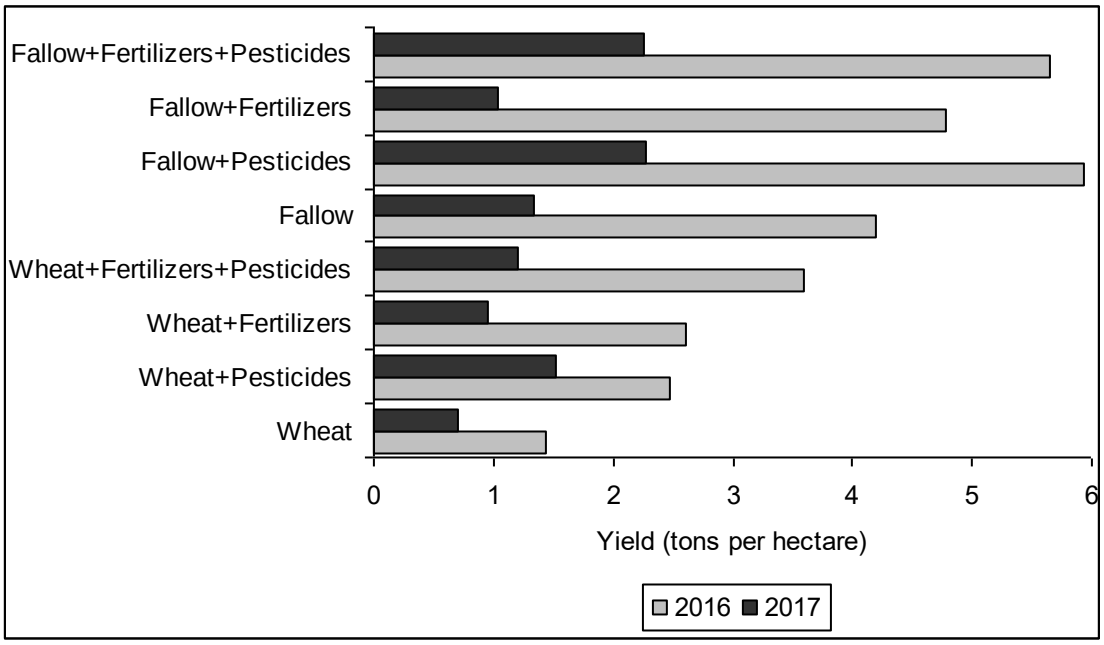

Figure 1. Yield of wheat in different variants of the experiment in 2016 and 2017.

Analysis of results (table 2, 3) by factorial ANOVA revealed that the yield mostly depends on the previous crop and pesticides, whereas the fertilizer demonstrated relatively slight effect in 2016 and no significant effect in 2017. Effect size of previous crop varied from 70.9% in 2016 to 32.1 in 2017. Effect size of pesticides varied from 14.0 in 2016 to 51.6% in 2017, whereas effect size of fertilizer did not exceed 4.5%. The interaction effects between the factors were either slight either non-significant.

In both 2016 and 2017 usage of fallow without chemical fertilisers provided statistically significantly higher yield than most of variants with fertilisers and pesticides where wheat was used as a previous crop. The only exception in 2016 was the variant "Wheat+Fertilizers+Pesticides" which provided lower yield then the variant "Fallow" (3.60 vs 4.19 tons per hectare) but the difference was insignificant. In

2017 non-significant differences were observed between "Wheat+Fertilizers+Pesticides" and "Fallow" and between "Wheat+Pesticides" and "Fallow" (table 4).

Table 2. Factorial ANOVA of the results of experiment.

Factor	Statistical significance		Effect size (%)	
	2016 year	2017 year	2016 year	2017 year
Previous crop	<0.001	<0.001	70.9	32.1
Fertilizers	<0.01	no	4.5	0.7
Pesticides	<0.001	<0.001	14.0	51.6
Previous crop*Fertilizers	<0.05	no	2.6	0.3
Previous crop*Pesticides	no	<0.001	0.2	5.7
Fertilizers*Pesticides	no	no	0.6	0.4
Previous crop*Fertilizers*Pesticides	no	<0.01	0.5	3.7

Table 3. Effects of previous crop, fertilizers and pesticides on the wheat yield in 2016 and 2017.

Factor	Factor value	2016			2017		
		Mean	-95.00%	+95.00%	Mean	-95.00%	+95.00%
Previous crop	Wheat	2.53	2.23	2.84	1.09	1.00	1.19
	Fallow	5.14	4.84	5.45	1.73	1.63	1.82
Fertilizers	No	3.51	3.20	3.81	1.46	1.36	1.55
	Yes	4.16	3.86	4.47	1.37	1.27	1.46
Pesticides	No	3.26	2.95	3.56	1.01	0.91	1.11
	Yes	4.42	4.11	4.72	1.81	1.71	1.91

Table 4. Post-hoc comparisons of yields in different variants of the experiment using Duncan's test.

				2016						
№	Previous crop	Fertilizers	Pesticides	1	2	3	4	5	6	7
1	Wheat	No	No		0.023	0.014	0.000	0.000	0.000	0.000
2	Wheat	No	Yes	0.023		0.730	0.017	0.001	0.000	0.000
3	Wheat	Yes	No	0.014	0.730		0.028	0.002	0.000	0.000
4	Wheat	Yes	Yes	0.000	0.017	0.028		0.169	0.000	0.013
5	Fallow	No	No	0.000	0.001	0.002	0.169		0.001	0.161
6	Fallow	No	Yes	0.000	0.000	0.000	0.000	0.001		0.016
7	Fallow	Yes	No	0.000	0.000	0.000	0.013	0.161	0.016	
8	Fallow	Yes	Yes	0.000	0.000	0.000	0.000	0.003	0.497	0.050
				2017						
1	Wheat	No	No		0.000	0.066	0.002	0.000	0.000	0.023
2	Wheat	No	Yes	0.000		0.001	0.039	0.198	0.000	0.004
3	Wheat	Yes	No	0.066	0.001		0.089	0.015	0.000	0.519
4	Wheat	Yes	Yes	0.002	0.039	0.089		0.326	0.000	0.232
5	Fallow	No	No	0.000	0.198	0.015	0.326		0.000	0.047
6	Fallow	No	Yes	0.000	0.000	0.000	0.000	0.000		0.000
7	Fallow	Yes	No	0.023	0.004	0.519	0.232	0.047	0.000	
8	Fallow	Yes	Yes	0.000	0.000	0.000	0.000	0.000	0.921	0.000

Average for two years cost efficiency of variant with fallow was 20.8% what is comparable with cost efficiency of the most cost effective variants (fallow as a as a previous crop + pesticides with cost efficiency of 36.6% and wheat as a previous crop + fertilizers with cost efficiency of 30.4%) (Figure 2).

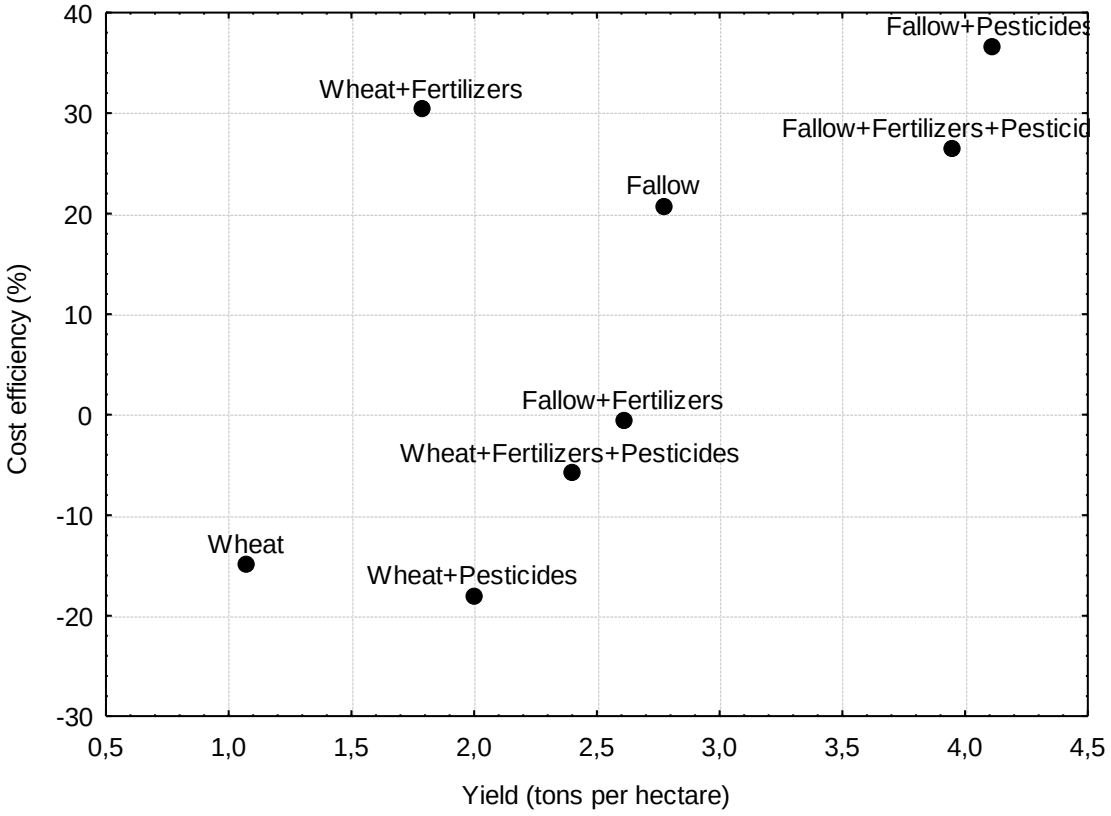

Figure 2. Average yield and average cost efficiency in different variants of experiment.

Basing on the results of our experiment we can recommend is the use of fallow in crop rotation scheme as cost-effective way to reduce the environmental impact of wheat production in Siberia

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