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Are intensification and winter wheat yield increase efficient?

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ABSTRACT

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The results of small-plot field trials of international comparisons of a series of crop management practices for winter wheat grown during 2014–2016 on fertile soils of Central Moravia were assessed. The objective of the experiments was to obtain the highest gross margin (GM), which is the difference between revenues and direct costs. The analyses showed that an optimal level of inputs and costs for obtaining the highest GM could exist. In the assessed series of crop management practices, the optimum input costs corresponded to 11 000–12 000 CZK/ha and 6–9 input measures. At high levels of grains (above 10 t/ha), higher values of GM were obtained by increased efficiency of inputs, but not by increasing their amount to maximize the yields. This indicates the multifunctional and synergic effects of production factors, which can be used at the so-called ecological intensification. Optimizations of inputs can be obtained rather by crop protection than by crop nutrition, which means rather in protection of high yields than in their maximization. Under field conditions, soil and plant processes affected by weather cannot be controlled. Therefore, optimisation of production factors is based both on scientific findings and practical agronomic experience. That is why a universal crop management practice with increased economic and ecological effects cannot be practically proposed.

Keywords: optimisation of crop management; ecological intensification; cost of crop nutrition and protection; grain quality

Winter wheat is the most abundant crop in the temperate zone. The way of its cultivation affects the economy, but also the environment in many countries and regions. Certain yield stagnation was reported from agrarian developed countries in Europe at the beginning of the third millennium (Brisson et al. 2010, Petersen et al. 2010, Alhemayer and Friedt 2012). In those countries, after 2010 this led to the formation of initiatives concentrated on wheat yield increase, supported by companies producing agrochemicals (Yield Enhancement Network, http://www.yen.adas.co.uk/; wheat yield initiative, https://agrar.bayer.de/Aktuelles/Nachrichten/2015/02/Yara.aspx; Naumheim and Ortseifen 2016). These efforts are predominantly oriented to the increased utilisation of yield potential of crop cultivars by intensification based on the use of reserves in plant nutrition and protection. Also other activities were observed focused on the reduction of agrochemicals use in plant production (Nitrate Directive, EU Directive 2009/128/EC). They are part of the trend towards reduction of negative impacts of crop management practices on the environment (Stoate et al. 2009). This should ensure application of conception of the so-called ecological intensification (Cassman 1999, Dobré et al. 2011, Pretty and Bharucha 2014), which is based on a balanced employment of economic and ecological requirements.

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However, for wheat growers, the primary goal is profit (Gasson 1973), which can be affected either by the yield or by grain quality and the costs of crop management practices. Moreover, the interest of farmers in optimisation of crop management practices increases the variation in wheat grain prices (Wright 2011).

The issue of efficiency of crop management practices is usually assessed by their mutual comparisons in polyfactorial small-plot field trials, in which one or several variants of crop management practices are tested; yet, such analyses detect only a part of interactions in the system E × G × M (E – environment; G – genotype/cultivar; M – crop management).

However, this type of experiments cannot include large numbers of factors, their levels and their combinations that have to be taken into account by a crop-grower under field conditions. Therefore, in the recent years the so-called 'competitions' or 'comparisons' of the major crop (cereals, rapeseed) management practices have spread abroad and in the Czech Republic. In these competitions individual participants (usually institutions or companies) show their knowledge and experience, but predominantly they exhibit their ability to use effectively production factors (Rossberg 2010, 2017). In these types of small-plot field trials, only one factor is being assessed, namely the crop management practices as an integral unit of growing measures and their interactions proposed by individual participants (usually persons with above-standard knowledge and practical experience in growing a particular crop). The assessing criterion is usually the gross margin as a difference between revenues and direct costs.

This paper is oriented to testing of the possibilities of efficient intensification of crop management practices for winter wheat by means of a suitable selection and optimization of agrochemicals' use for crop nutrition and protection.

MATERIAL AND METHODS

The results of small-plot field trials were assessed based on the international comparisons of crop management practices of winter wheat carried out during three seasons 2013/2014, 2014/2015 and 2015/2016 by the Agrotest Fyto, Ltd. in sugar-beet growing region of Central Moravia with rapeseed as a preceding crop in all tested years (Table 1).

Predominantly institutions from the Czech Republic but also from Slovakia and Poland took part in this competition, which presented in most cases two crop management practices. The participants had the choice of cultivar and seeding rate that ranged between 200 and 450 seeds/m^2. Further, they proposed the crop management practices, which were carried out by the technicians of the Agrotest Fyto, Ltd. in small-plot trials with four randomized repetitions with plot size of 10 m^2 (5 × 2 m). Sowing was carried out by sowing machine of the type Oyord (Wintersteiger, Ried, Austria) and harvest by small-plot harvester Sampo-Rosenlew SR 2010 (Pori, Finland). Records were carried out for individual variants concerning the date of treatment, growth stage (BBCH), type and amount of agrochemicals applied. The prices of agrochemicals were determined according to the price list of the regional seller (Navos a.s., http://www.navos-km.cz/). The price of an agrochemical application in a solid form was determined to be 250 CZK/ha and in a liquid form 300 CZK/ha. The total direct costs (CZK/ha) were determined for

Table 1. Characteristics of experimental localities

Parameter	Pravčice	Kroměříž	Kroměříž
Geographical situation	49°19'16''N, 17°29'353''E	49°17'7''N, 17°21'30''E	49º 16'56''N, 17º21'37''E
Soil type	Gleyic Fluvisol	Luvic Chernozem	Luvic Chernozem
Texture class	Silty clay	Silty clay loam	Silty clay loam
Altitude (m a.s.l.)	201	235	248
Average annual temperature (°C)	11.0	10.8	11.1
Annual sum of precipitations (mm)	575.5	401.8	550.2
Number of variants	46	51	56
Date of sowing	3. 10. 2013	4. 10. 2014	7. 10. 2015
Date of harvest	23. 7. 2014	24. 7. 2015	22. 7. 2016

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individual variants of crop management practices as the sum of costs for individual management treatment comprising application of agrochemicals and direct costs for plant nutrition and protection. Costs for crop management practices carried out uniformly for all the variants under comparison were not considered in calculations (soil treatment, sowing and grain harvest, uniform application of insecticides in all variants). Modifications were carried out in about 50% of inputs that are real in agricultural practice.

Grain yields were calculated for 14% humidity and parameters of grain quality were determined in the laboratory, namely the crude protein (%) and bulk density (kg/100 L). Grain price was determined based on grain quality. Multiplication of yield (t/ha) and grain price (CZK/t) gave the revenues (CZK/ha). Consequently, gross margin (GM) was calculated as the difference between revenues and direct costs (CZK/ha). The goal and major criterion in comparisons of individual variants of crop management practices was to obtain the highest value of gross margin. The values of GM were relatively high due to the fact that only measures which were not executed in a generalized way and were different in individual variants were included in direct costs. The indicative exchange rates are 1 EUR = 26 CZK, 1 USD = 22 CZK.

The data were processed using the basic statistical characteristics, correlation and regression analyses in the statistical programme of Microsoft Office Excel 2013 (Redmond, USA). The crop management practices were proposed by the participants for soil and weather conditions in individual years, and the grain price was always known only after harvest; interpretation of the results was thus predominantly carried out based on individual years.

RESULTS AND DISCUSSION

The gross margin value depends on revenues and direct costs. The revenues are affected by the yield and grain quality. In practice, grain quality is predominantly determined based on the contents of N-substances and bulk density of grain. Other characteristics, such as gluten content and sedimentation value are rather genetically determined. Direct costs reflex crop management practices during vegetation. Variability of these characteristics (Table 2) indicates possibilities of their changes by the modification of crop management practices.

In all years, the greatest values of coefficient of variation (*CV*) were recorded in direct costs as a result of different crop management practices, namely the selection of cultivars and combination of production factors (seeding rate, type and amount of fertilizer, pesticide and growth regulators). This can be considered as the major source of GM differences. The values of *CV* of the number of input measures within individual crop management practices and partial costs for plant nutrition and protection confirm this thesis (Table 2).

In all years, *CV* of revenues was lower by one order of magnitude (about 15%) than *CVs* of indicators which characterize the input costs. Also, the *CVs* of indicators having impact on revenues (yield, content of crude protein in grain and bulk density of grain) were slightly lower than *CV* of revenues.

Highly significant correlations of GM with revenues, yields and grain price were found in all years. Other relationships differed among years in the character and significance of correlations (Table 3).

Increased cost of inputs characterizing intensification should ensure increased yields. This was confirmed by significant positive correlations of total costs and the number of input measures with grain yields in 2014 and 2015. However, in 2016 this correlation was very weak and negative (Table 4). In 2014, yield was more affected by the costs for nutrition and in 2015 by the cost for crop protection.

Cost increase had a significant positive effect on the content of crude protein in 2014 and 2016; the effect on bulk density of grain was insignificantly negative. Only significant negative correlations between the number of input measures and the bulk density of grain were obtained in 2014 (Table 4).

The relationship between yield and both characteristics of grain quality was mostly negative but insignificant. Statistical significance was only detected in bulk density in 2014 ($r = -0.321^*$) and the content of crude protein in grain in 2016 ($r = -0.266^*$).

The results show that intensification implemented by costs increase affects differently the indicators of GM. This indicates a number of interactions, both positive and negative. Thus, the low values of linear correlation coefficients between costs and GM can be explained (Table 3). Description of this relationship by a second order polynomial function (Figure 1) showed that its determination was low in all years. The curves

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Table 2. Basic statistical data of the assessed characteristics in 2014–2016

Characteristic	Harvest year	Average	Minimum	Maximum	Median	Coefficient of variation (%)
Total direct costs (CZK/ha)	2014	10 939	7225	15 618	10 782	22.26
	2015	11 548	5688	17 438	11 559	24.58
	2016	11 693	7173	15 789	11 742	16.77
	2014–2016	11 416	5688	17 438	11 461	21.33
Costs for nutrition (CZK/ha)	2014	5035	2727	7320	5116	26.29
	2015	6183	3402	12 801	5833	33.93
	2016	5901	3788	9023	5798	22.94
	2014–2016	5759	2727	12 801	5671	29.39
Costs for protection (CZK/ha)	2014	5890	3109	9051	5579	26.41
	2015	5354	2010	9685	4979	32.60
	2016	5539	2595	7607	5602	22.65
	2014–2016	5615	2011	9685	5395	27.96
No. of input measures	2014	8.24	5	12	8	24.03
	2015	7.63	4	11	8	22.48
	2016	8.04	6	12	8	16.90
	2014–2016	7.96	4	12	8	21.41
Revenues (CZK/ha)	2014	52 162	42 009	58 480	52 220	8.21
	2015	54 751	45 399	61 614	54 279	7.68
	2016	38 854	32 368	43 872	38 688	8.34
	2014–2016	48 154	32 368	61 614	49 802	16.94
Gross margin (CZK/ha)	2014	41 223	31 784	48 116	41 899	9.25
	2015	43 203	36 026	49 709	43 189	7.97
	2016	27 161	16 821	32 907	27 579	12.71
	2014–2016	36 736	16 821	49 709	36 617	22.22
Grain yield (t/ha)	2014	13.24	10.86	14.62	13.18	6.44
	2015	13.90	12.30	15.10	14.00	5.22
	2016	12.74	10.86	13.73	12.92	5.16
	2014–2016	13.28	10.86	15.10	13.20	6.68
Grain price (CZK/t)	2014	3939	3300	4000	4000	5.01
	2015	3941	3700	4300	3800	6.38
	2016	3050	2800	3200	3200	6.42
	2014–2016	3614	2800	4300	3700	13.32
Crude protein content (%)	2014	12.57	11.07	14.09	12.51	5.55
	2015	11.94	10.70	13.60	11.80	5.54
	2016	12.95	10.80	15.49	12.90	6.67
	2014–2016	12.50	10.70	15.49	12.46	6.89
Bulk density of grain (kg/100 L)	2014	79.86	76.10	84.00	79.80	1.66
	2015	82.39	77.60	84.60	82.40	1.47
	2016	77.47	69.90	81.60	77.85	2.76
	2014–2016	79.83	69.90	84.60	79.90	3.36

in Figure 1 show that the greatest values of GM were obtained at average costs in 2014 and 2015 and at low costs in 2016. Table 5 shows percentage expression of the level of yields and inputs corresponding to the three groups with the highest obtained GM values (the first, the first three, the

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Table 3. Correlations of selected characteristics with gross margin (CZK/ha)

Characteristic	2014 (n = 46)	2015 (n = 51)	2016 (n = 56)	2014–2016 (n = 153)
Revenues (CZK/ha)	0.825**	0.742**	0.837**	0.995**
Direct costs (CZK/ha)	–0.115	–0.114	–0.395**	–0.151
Costs for nutrition (CZK/ha)	0.069	–0.281*	–0.378**	–0.118
Costs for protection (CZK/ha)	–0.243	0.146	–0.194	–0.008
No. of input measures	0.025	0.260	–0.228	–0.031
Grain yield (t/ha)	0.680**	0.374**	0.610**	0.648**
Purchase price (CZK/t)	0.471**	0.598**	0.599**	0.908**
Bulk density of grain (kg/100 L)	0.056	0.165	0.581**	0.727**
Crude protein content (%)	0.052	0.542**	–0.397**	–0.381**

*$P \leq 0.05$; **$P \leq 0.01$

first five). It shows the yields and costs for cultivation practices using which the highest GM values were obtained, in comparison with the average level of the yield and input indicators. This table reveals the following:

– the first 5 highest GM values were obtained due to the above-average yields in all three years with a small exception in 2015;
– the first 5 highest GM values were obtained due to the below-average total costs of inputs in 2014 and 2016, in 2015 it agreed with the second highest GM value of 104% and the third highest value of 115% with the average total cost of inputs;
– interestingly enough, the highest GM values were obtained in 2014 and 2015 with significantly below-average costs for crop protection and the above-average costs for crop nutrition;
– in 2016, the first three highest GM values were obtained due to the below-average costs for crop nutrition and protection;
– GM in the second to the fifth place in 2014 and 2015 were obtained rather due to the below-average costs for nutrition; the costs for protection were also mostly below-average with the exception of 2015 when the costs of the second highest GM value were 108% and the third highest GM 138% of the average. Protection was carried out especially against powdery mildew (*Blumeria graminis*), DTR (*Dreschlera tritici-repentis*), septoriosis (*Septoria nodorum* and *Septoria*

Table 4. Correlations between input costs, yield and grain quality characteristics

Characteristic	Year	Costs (CZK/ha)			Number of input measures
		total	for nutrition	for protection	
Yield (t/ha)	2014	0.328*	0.457**	0.130	0.431**
	2015	0.396**	0.194	0.417**	0.451**
	2016	–0.031	–0.170	0.136	–0.089
	2014–2016	0.205*	0.178*	0.182*	0.194*
Crude protein content (%)	2014	0.303*	0.220	0.273	0.238
	2015	0.235	0.135	0.227	0.306*
	2016	0.335*	0.360**	0.124	0.029
	2014–2016	0.245**	0.142	0.194*	0.210*
Bulk density of grain (kg/100 L)	2014	–0.259	–0.276	–0.172	–0.288
	2015	–0.083	–0.198	0.101	0.023
	2016	–0.021	–0.184	0.167	0.169
	2014–2016	–0.079	–0.063	–0.011	–0.081

*$P \leq 0.05$; **$P \leq 0.01$

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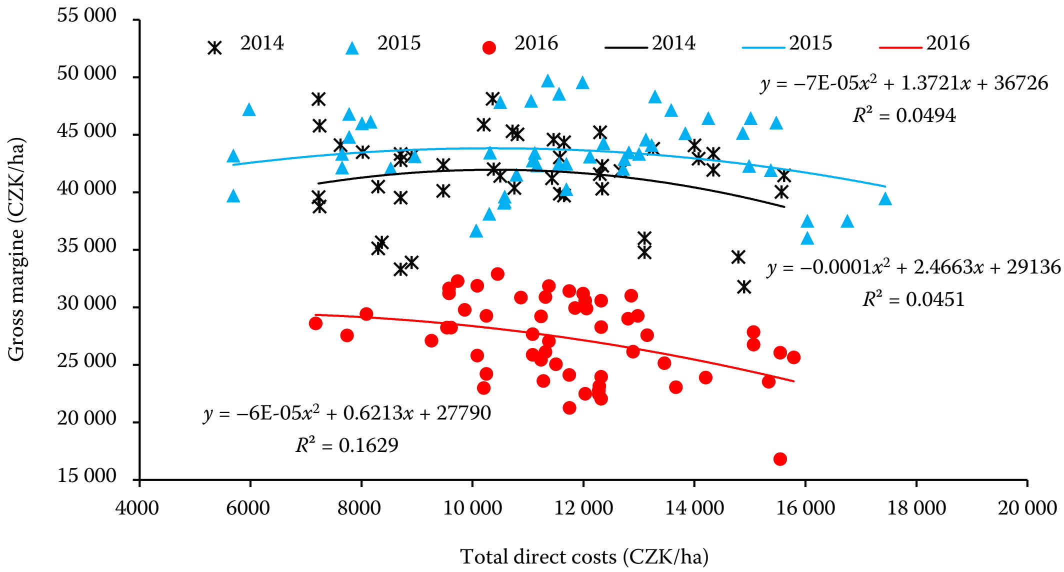

Figure 1. Relation between total direct input costs and gross margin in individual years (2014, 2015, 2016)

tritici), rusts (*Puccinia striiformis* and *Puccinia recondita*) and fusariosis of ears (*Fusarium* spp.).

Correlations between the number of input measures within crop management practices and their costs were highly significant in all three years. The assumption of the increase of GM values by the reduction of the number of input measures cannot be unambiguously confirmed based on the correlations in Tables 3 and 4. The highest GM values were obtained in 2014 and 2016 by means of 8 input measures, and in 2015 implying 9 input measures. In all three years, the 5 highest GM values were obtained by crop management practices with 6–9 input measures.

Table 5. Percentage expression of values in selected characteristics in relation to the three groups with the highest gross margin (GM) values (CZK/ha)

Characteristic	Year	First	First to third*	First to fifth*	Average	Min/max (% of average)
GM (CZK/ha)	2014	48 116	45 878	45 317		
	2015	49 709	48 327	47 838		
	2016	32 907	31 868	31 641		
Grain yield (t/ha)	2014	110	104–110	100–110	13.24	82/110
	2015	104	104–106	100–106	13.90	88/109
	2016	106	103–106	101–106	12.74	85/108
Total costs (CZK/ha)	2014	95	66–95	66–98	10 939	66/143
	2015	98	98–115	91–115	11 548	49/151
	2016	89	83–89	82–97	11 693	61/135
Costs for nutrition (CZK/ha)	2014	122	59–122	59–122	5035	54/145
	2015	116	96–116	87–116	6183	55/207
	2016	99	72–99	72–99	5901	64/153
Costs for protection (CZK/ha)	2014	72	72–94	53–103	5890	53/154
	2015	78	78–138	78–138	5354	38/181
	2016	82	82–99	75–107	5539	47/137
Number of input measures	2014	97	73–97	73–97	8.24	65/146
	2015	118	118	92–118	7.63	52/144
	2016	100	75–100	75–112	8.04	75/149

*in GM, the lowest values in the group are given, because the highest value is given in the first group

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It is important for growers to recognize the economic ceiling i.e. the maximum yields that make economic sense, given by the relative prices of input and outputs, marketability, risk and other factors (Sumberg 2012). Yield at the agronomic optimum may well be less than the attainable yield and is likely to be significantly less than the biophysical maximum (Bryan et al. 2014). Agronomic optimum can differ according to the soil-weather conditions and crop management practices but also by the degree of risk to obtain it (Loyce et al. 2012). The evaluation of crop management systems has been based principally on yield, together with profitability (Meynard and Girardin 1991); under the assumptions of cumulative effect of production factors and that high yields generate high profitability.

The analyses showed that an optimal level of inputs and costs for obtaining the highest GM could exist. In the assessed series of crop management practices, optimal input costs corresponded to 11 000–12 000 CZK/ha (Figure 1) and 6–9 input measures (Tables 2 and 5). At high levels of grain yields (above 10 t/ha), greater GM values were obtained by increased efficiency of inputs and not by their increase with the aim to maximize yields. Therefore, multifunctional and synergic effects of production factors (which can be used at ecological intensification) can be assumed.

In accordance with the conclusions of Loyce et al. (2012), the results showed that greater reserves of costs optimization are in crop protection compared to crop nutrition, it means in protection of high yields rather than in their maximisation.

The effort to obtain good outputs in this comparison of crop management practices results in a constant improvement of the proposed growing measures by the participants. Thus the decrease of variability in total direct costs and grain yields from 2014 to 2016 can be explained (Table 2). A relatively small variability of yields at their high levels was the consequence of weather course that was favourable for formation of cereal yields in recent three years together with an educational impact of this competition on its participants and on the community of cereal growers.

REFERENCES

Alhemeyer J., Friedt W. (2012): Winter wheat yields in Germany are stable at a high level. Getreidemagazin, 6: 38–41. (In German)

Brisson N., Gate P., Gouache D., Charmet G., Oury F.-X., Huard F. (2010): Why are wheat yields stagnating in Europe? A comprehensive data analysis for France. Field Crops Research, 119: 201–212.

Bryan B.A., King G., Zhao G. (2014): Influence of management and environment on Australian wheat: Information for sustainable intensification and closing yield gaps. Environmental Research Letters, 9: 0444005, 12. Available at http://iopscience.iop.org/1748-9326/9/4/044005

Cassman K.G. (1999): Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proceedings of the National Academy of Sciences of the United States of America, 96: 5952–5959.

Doré T., Makowski D., Malézieux E., Munier-Jolain N., Tchamitchain M., Tittonell M. (2011): Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge. European Journal of Agronomy, 34: 197–210.

Gasson R. (1973): Goals and values of farmers. Journal of Agricultural Economics, 24: 521–542.

Loyce C., Meynard J.M., Bouchard C., Rolland B., Lonnet P., Bataillon P., Bernicot M.H., Bonnefoy M., Charrier X., Debote B., Demarquet T., Duperrier B., Félix I., Heddadj D., Leblanc O., Leleu M., Mangin P., Méausoone M., Doussinault G. (2012): Growing winter wheat cultivars under different management intensities in France: A multicriteria assessment based on economic, energetic and environmental indicators. Field Crops Research, 125: 167–178.

Meynard J.M., Girardin Ph. (1991): Produce otherwise. Le courrier de l´environnement de l´INRA, 15: 1–19. Available at: http://www.inra.fr/dpenv/meynac15.htm (In French)

Naunheim H.P., Ortseifen U. (2016): Wheat yield initiative: There's something else! Getreide Magazin, 1: 70–72. (In German)

Petersen J., Haastrup M., Knudsen L., Olesen J.E. (2010): Causes of yield stagnation in winter wheat in Denamark. DJF Report Plant Science, 147: 149.

Pretty J., Bharucha Z.P. (2014): Sustainable intensification in agricultural systems. Annals of Botany, 114: 1571–1596.

Roßberg R. (2010): Yield was not decisive. DLG-Mitteilungen, 12: 94–97. (In German)

Roßberg R. (2017): DLG wheat comparison. The results of Haßfurt. DLG-Mitteilungen, 3. Available at: http://www.dlg-mitteilungen.de/mediathek/downloads (In German)

Stoate C., Báldi A., Beja P., Boatman N.D., Herzon I., van Doorn A., de Snoo G.R., Rakosy L., Ramwell C. (2009): Ecological impacts of early 21st century agricultural change in Europe – A review. Journal of Environmental Management, 91: 22–46.

Sumberg J. (2012): Mind the (yield) gap(s). Food Security, 4: 509–518.

Wright B.D. (2011): The economics of grain price volatility. Applied Economic Perspectives and Policy, 33: 32–58.

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