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The effect of mineral fertilisers and farmyard manure on grain and straw yield, quality and economical parameters of winter wheat

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Abstract: In the years 2011–2014, winter wheat grain yield, qualitative and economic parameters were evaluated according to different fertiliser treatments: (1) control: unfertilised treatment; (2) farmyard manure (FYM) and (3) FYM + NPK (farmyard manure applied together with mineral NPK). The highest yields (8.10 t/ha) were recorded in the FYM + NPK treatment, while significantly lower yields (6.20 t/ha and 5.73 t/ha) were recorded in FYM and control treatments, respectively. Similarly, statistically significantly higher values of the quality parameters were found in the FYM + NPK treatment (13.55% of crude protein content and 43.56 mL of Zeleny's sedimentation test), compared to control (10% and 22.44 mL, respectively). The modelling expert system (AGROTEKIS-Crop Technology and Economy) was used for the evaluation of economy. This software is based on technological methods of cultivation and norms of material input costs and costs of individual mechanised works. The economic benefits and profitability were evaluated for three different levels of grain market price. The highest gross profit per ha was recorded in the FYM + NPK treatment. According to the gross profit, the control treatment provided better results than the FYM treatment.

Keywords: *Triticum aestivum* L.; organic manure; financial costs; mineral nutrients; principal component analysis

Wheat is the most important cereal crop in the Czech Republic, covering approximately 820 thousand ha out of 2.5 million hectares of sown land in 2018 (Czech Statistical Office 2019). It is a crucial source of carbohydrates, proteins, minerals and fibre for the mankind as well as animals, mainly processed as leavened or unleavened bakeries, compounds of food additives, or feedstuff. Wheat straw is an important material with many possibilities of utilisation, such as straw bedding, the compound of organic manures or a separate organic fertiliser (Yin et al. 2018), or primary material for bioenergy purposes (Townsend et al. 2018).

The wheat grain yield and its quality is however producers' main concern, both parameters significantly affecting their economic situation. To achieve the highest possible yields and grain quality, farmers can apply and combine wide range of agronomical measures, such as fertilisation with organic manures and mineral fertilisers (López-Bellido et al. 1998, Hejcman and Kunzová 2010, Li et al. 2018, Yin et al. 2018), crop rotation (López-Bellido et al. 1998, Kunzová and Hejcman 2010, Shahzad et al. 2016) and different production practices (López-Bellido et al. 1998, Wang et al. 2018).

Every year, most of the sowing area in the Czech Republic is sown with wheat intended for human nutrition, which is priced higher if the requirements of the wheat processors are met. The main parameter is grain protein content, influencing loaf volume of bread (Bushuk 1997). The concentration of proteins in wheat grain is affected by genotype, soil-climate conditions and cropping practices. According to Shewry (2007), the protein content in wheat may vary from 7%

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to 22% and the genetic background is responsible for one-third of the content, which means that the rest is influenced by external factors. These main factors are precipitation and fertilisation. The lack of precipitation during the growing season leads to high protein content and increased vitreousness (Rao et al. 1993, López-Bellido et al. 1998, Rharrabti et al. 2003), while seasons with abundant precipitation provide grain with low content of proteins (Gürsoy et al. 2010, Flagella et al. 2010). As to fertilisation, grain protein content is influenced mostly by the application of nitrogen (Wieser and Seilmeier 1998, Johansson et al. 2001).

The quality of wheat grain is rated according to several criteria defined in the CSN 46 1100-2 Food grain – Food wheat. This standard divides grain into two groups, first for leavened and second for unleavened bakeries, with differences in crude protein content (CPC) and Zeleny's sedimentation test (ZST). While the first category has to contain at least 11.5% of CPC and the value of the ZST 30 mL, the second category has to contain maximally 11.5% of CPC and the value of ZST shall not exceed 25 mL. The qualitative parameters significantly influence the final price a farmer gets for his harvest. The prices vary significantly according to location, usually increase with each per cent of CPC and fluctuate significantly during the season.

This paper evaluates the effect of three different fertiliser treatments (unfertilised control, farmyard manure – FYM, and combination of farmyard manure with mineral NPK (FYM + NPK) over four years (2011–2014) on grain and straw yields of winter wheat (cv. Mulan), crude protein content and Zeleny's sedimentation test value. Financial analysis was also calculated, evaluating basic financial indicators of different fertilisers' application and their effect on farmer's finance.

MATERIAL AND METHODS

Site description. The experiment is located in Ivanovice na Hané (South Moravian Region, the Czech Republic, 49°19'N, 17°05'E) and was established in 1956. The altitude of the experimental site is 225 m a.s.l. The soil type is loamy and degraded chernozem. The long-term mean temperature and precipitation are 8.4 °C and 555 mm, respectively.

Experimental design. The experiment consists of four fields. Each field is divided into 48 experimental plots, where 12 fertiliser treatments in 4 replications are arranged in a completely randomised block design. The size of the plot is 8 × 8 (64 m^2). The crop rotation consists of *Hordeum vulgare* L. (spring form with *Medicago sativa* L. underseeding), *Medicago sativa* L., *Triticum aestivum* L. (winter form), *Zea mays* L., *Hordeum vulgare* L. (spring form), *Brassica napus* L., *Triticosecale* Wittm. and *Solanum tuberosum* L. Three out of 12 fertiliser treatments are evaluated in this paper: unfertilised control; farmyard manure and combined application of FYM with mineral fertilisers. The FYM was applied during the autumn before potatoes were planted, and the dose was 40 t/ha (approximately 200, 56 and 236 kg N, P and K per ha, respectively). As winter wheat was the third crop after potatoes in the crop rotation, the estimated dose of nutrients available to wheat from the farmyard manure (applied to potatoes) is approximately 10% of the total applied amount – 20, 6 and 24 kg N, P and K/ha, respectively. Mineral N, P and K were applied as calcium ammonium nitrate (27% N), triple superphosphate (19.4% P) and potassium chloride (49.8% K) at doses 120, 26 and 50 kg/ha, respectively (pure nutrient inputs). The nitrogen was applied in three equal dressings (in autumn before sowing, during February or at the beginning of March for regeneration, and at the beginning of May for the grain production). P and K fertilisers were applied in October before the autumn sowing. For the purpose of this article, yields and qualitative parameters of winter wheat harvested from 2011 to 2014 were evaluated. The harvest was carried out in different experimental fields each year. The winter wheat was sown during the first half of October. The depth of sowing was 3 cm. The row distance was 12.5 cm. The sowing rate was 400 seeds per m^2. The wheat cultivar used in this experiment was Mulan, a highly yielding, short straw cultivar, registered in the Czech Republic as A class cultivar. Growth regulators have not been used since the beginning of the trial.

Grain yield and grain quality analysis. The size of the experimental plot was 8 × 8 m, but only the 5 × 5 central area of the plot was used for evaluation of grain and straw yield. The grain was harvested with a small-plot combine harvester (HEGE 180, Ried im Innkreis, Austria). The crude protein content was analysed according to the Kjeldahl method (ČSN EN ISO 20483, 2007). The Zeleny's sedimentation test value was measured according to the ČSN ISO 5529, 2011. Both analyses were performed at the Gene bank laboratory, Crop Research Institute, Prague.

Statistical analysis. The statistical analyses were performed by Statistica 13.3 (TIBCO Software, Palo

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Alto, USA). The effect of the year, treatment and year × treatment interaction were analysed *via* one-way (ANOVA) and factorial analysis of variance (MANOVA), followed by the Tukey's *HSD* (honestly significant difference) post hoc test. The principal component analysis was also performed for graphical presentation of the results.

Financial analysis. The economic evaluation was based on technological processes of cultivation and normative costs of material inputs and costs of individual mechanised work (Tables 1 and 2). Prices used for the evaluation refer to the year 2018. Based on the grain and straw yields obtained in the analysed fertiliser treatments, the costs, economic benefits and profitability of winter wheat cultivation were modelled and evaluated in terms of three levels of the market price of food grain per tonne of production (160 EUR/t; 180 EUR/t and 200 EUR/t). According to the grain qualitative analyses, the control and FYM fertiliser treatments did not provide a sufficient amount of nutrients to create a high CPC level (over 11.5%). Therefore, this grain could be sold only as feedstuff wheat, and the market price was reduced by 9.2 EUR/t according to the Czech Statistical Office (2019). On the other hand, the FYM + NPK treatment was priced higher, 12 EUR/t, due to higher mean CPC. The variable costs were determined from the technological procedures and the fixed costs were determined for all variants uniformly at EUR 260/ha according to the site conditions of the field experiments (including mainly land costs – the rent for agricultural land, agricultural land tax, depreciation of buildings, manufacturing and general expenses). The total value of production was determined based on the yields using three models of the food-processing wheat market price. Based on the value of total costs and production, the resulting economy was evaluated for each fertiliser treatment – gross profit per hectare, cost-effectiveness, and the amount of harvest needed to achieve zero cost-effectiveness. The material, mechanisation, variable and total costs for each fertiliser treatment are shown in Table 3. The AGROTEKIS-Crop Technology and Economy software was used for the economical evaluation in this paper.

RESULTS AND DISCUSSION

The grain yield was significantly affected by fertiliser treatment ($P < 0.001$), year ($P < 0.001$) and

Table 1. The list of agro-technical operations, frequency and material inputs and costs

Agro-technical operation	UM	Frequency	Material inputs	Dose (UM/ha)	Price (EUR/UM)	Costs (EUR/ha/year)
Transport and spreading of the limestone (1.5–2.0 t/ha)	(t)	0.25×	finely ground limestone	2	21.04	10.5
Transport and spreading of the FYM	(t)	0.25×	farmyard manure	40	10	100
Transport and spreading of fertilisers	(t)	1.00×	superphosphate	0.42	102.1 + 39.5	141.6
Sowing	(t)	1.00×	seeds	0.20	402	80.4
Spreading of herbicides	(kg)	1.00×	herbicides	0.15	218.2	32.7
Transport and spreading of fertilisers	(t)	1.00×	calcium ammonium nitrate	0.15	279.3	41.9
Spreading of herbicides	(L)	1.00×	herbicides	1.50	8.2	12.4
Transport and spreading of fertilisers	(t)	1.00×	calcium ammonium nitrate	0.15	279.3	41.9
Spreading of fungicides	(L)	1.00×	fungicides	0.20	60	12
Transport and spreading of fertilisers	(t)	1.00×	calcium ammonium nitrate	0.15	279.3	41.9
Harvest	(t)	1.00×	winter wheat grain	8.10	168.5	0
Straw pressing	(t)	1.00×	winter wheat straw	8.08	20	0
Costs						515.3

UM – unit of measure; FYM – farmyard manure

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Table 2. The standards (hours and fuel consumption per ha) and financial costs of agricultural mechanisation

Agricultural mechanisation	UM	Standards			Costs (EUR/UM/year)
		hours/UM	fuel consumption/UM	EUR/UM	
Self-propelled spreader	(ha)	0.48	5.50	19.6	4.9
Farmyard manure spreader	(ha)	1.33	25.00	93.4	23.4
Semi-trailed spreader	(ha)	0.27	4.00	14.7	14.7
Plough with eight blades	(ha)	0.56	18.00	55.3	55.3
Cultivator (8 m)	(ha)	0.16	9.20	23.8	23.8
Seeding machine (9 m)	(ha)	0.15	5.50	19.5	19.5
Self-propelled spreader	(ha)	0.13	1.80	9.2	9.2
Semi-trailed spreader	(ha)	0.15	2.00	9.2	9.2
Self-propelled spreader	(ha)	0.13	1.80	9.2	9.2
Semi-trailed spreader	(ha)	0.15	2.00	9.2	9.2
Self-propelled spreader	(ha)	0.13	1.80	9.2	9.2
Semi-trailed spreader	(ha)	0.15	2.00	9.2	9.2
Combine harvester (300 kW)	(ha)	0.38	18.00	84.9	84.9
Semi-trailer	(ha)	0.03	0.40	1.3	10.4
Straw pressing machine (1.8 m)	(ha)	0.45	8.50	33.8	33.8
Semi-trailer	(t)	0.06	0.60	2	16.2
Disk tiller (6 m)	(ha)	0.21	7.20	22.1	22.1
Total costs		4.19	96.28		364

UM – unit of measure

fertiliser treatment × year interaction ($P < 0.001$). The most important factor affecting the grain yield was year (74%), followed by fertiliser treatment (23%). Detailed results of grain yields as affected by all analysed factors are shown in Table 4.

The straw yield was significantly affected by fertiliser treatment ($P < 0.001$), year ($P < 0.001$) and fertiliser treatment × year interaction ($P < 0.001$). The most important factor affecting straw yield was year (78%), followed by fertiliser treatment (19%). Detailed results of straw yield as affected by the analysed factors are shown in Table 4.

Table 3. The material, mechanisation, variable and total costs (EUR/ha) according to the fertiliser treatment

	Control	FYM	FYM + NPK
Material costs	148.0	248.0	515.3
Mechanisation costs	290.8	315.9	364.0
Variable costs	438.8	563.9	879.4
Total costs	698.8	823.9	1 139.4

control – unfertilised treatment; FYM – farmyard manure; FYM + NPK – farmyard manure applied together with mineral NPK

The crude protein content was significantly affected by fertiliser treatment ($P < 0.001$) and year ($P < 0.001$). The most important factor was the fertiliser treatment (53%), while conditions of the year affected CPC by 45%. Detailed results are shown in Table 5.

The ZST was significantly affected by fertiliser treatment ($P < 0.001$), year ($P < 0.001$) and by fertiliser treatment × year interaction ($P < 0.05$). The fertiliser treatment was the most important factor (60%), followed by the year (39%). Detailed results are shown in Table 5.

The highest total costs were found at the treatment with FYM + NPK – 1 139.4 EUR/ha, while lower total costs were recorded in FYM treatment (823.9 EUR/ha), and control treatment (698.8 EUR/ha) (Table 3). The FYM + NPK treatment also recorded the highest gross profit per 1 ha (415.4 EUR, Table 6). In terms of gross profit, the control treatment was more preferred then the FYM treatment. Therefore, it is clear that part of the costs from the four-year fertilisation cycle is higher than the economic benefits from the crop yield increase. The control treatment also recorded higher gross profit (281.5 EUR), than the FYM treatment. More detailed data are summarised in Table 6.

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Table 4. The grain and straw yield as affected by fertiliser treatment and year

Fertiliser treatment	2011	2012	2013	2014	Means of the treatments
Grain yield (t/ha)					
Control	6.99 ± 0.08^{Ac}	2.89 ± 0.11^{Aa}	6.30 ± 0.11^{Ab}	6.72 ± 0.15^{Abc}	5.73 ± 0.43^{A}
FYM	7.91 ± 0.26^{Bc}	2.78 ± 0.08^{Aa}	6.87 ± 0.16^{Ab}	7.24 ± 0.20^{Abc}	6.20 ± 0.53^{AB}
FYM + NPK	10.98 ± 0.14^{Cd}	2.86 ± 0.09^{Aa}	8.71 ± 0.22^{Bb}	9.86 ± 0.23^{Bc}	8.10 ± 0.81^{B}
Means of the years	8.63 ± 0.52^{b}	2.84 ± 0.05^{a}	7.29 ± 0.32^{b}	7.94 ± 0.43^{b}	
Straw yield (t/ha)					
Control	6.24 ± 0.10^{Ab}	2.63 ± 0.12^{Aa}	6.94 ± 0.17^{Abc}	7.44 ± 0.24^{Ac}	5.81 ± 0.49^{A}
FYM	7.37 ± 0.21^{Bb}	2.56 ± 0.12^{Aa}	7.63 ± 0.23^{Ab}	7.97 ± 0.39^{Ab}	6.38 ± 0.58^{AB}
FYM + NPK	10.09 ± 0.28^{Cb}	2.80 ± 0.08^{Aa}	10.04 ± 0.30^{Bb}	9.39 ± 0.08^{Bb}	8.08 ± 0.80^{B}
Means of the years	7.90 ± 0.50^{b}	2.66 ± 0.06^{a}	8.20 ± 0.42^{b}	8.26 ± 0.29^{b}	

Means with the standard error of the mean followed by the same letter (A – vertically; a – horizontally) are not significantly different at the 0.05 probability level. control – unfertilised treatment; FYM – farmyard manure; FYM + NPK – farmyard manure applied together with mineral NPK

The principal component analysis separated two significant factors considerably affecting grain and straw yields and grain quality (Figure 1). According to horizontal axis (Figure 1), the year 2012 can be separate from the other years. The second factor was the fertiliser treatment, separating fertiliser treatments according to vertical axis (Figure 1).

Winter wheat grain and straw yields and grain quality are strongly affected by modifiable and non-modifiable factors. The modifiable factors are presented by farmer's approaches, including agronomical measurements, crop rotations, plant protection, and choice of cultivar or fertilisation. Concerning the fertilisation, three major groups of fertilisers can be applied to the field: organic manures, organic fertilisers and mineral fertilisers. Each group has a different origin, composition, benefits, effects, financial costs and side effects, such as environmental impacts (Mózner et al. 2012).

According to the results, the differences between control and FYM treatments were minimal. Application of the FYM in the crop rotation slightly increased the average grain (+0.47 t/ha) and straw (+0.57 t/ha) yield, when compared with the control treatment (Table 4). Comparing the CPC and ZST, no differences were recorded between the control and FYM treatments. This means that beneficial effects of nutrients released from FYM were utilised by

Table 5. The crude protein content (CPC) and Zeleny's sedimentation test (ZST) as affected by fertiliser treatment and year

Fertiliser treatment	2011	2012	2013	2014	Means of the treatments
CPC (%)					
Control	8.71 ± 0.23^{Aa}	12.54 ± 0.66^{Ac}	10.49 ± 0.19^{Ab}	8.25 ± 0.08^{Aa}	10.00 ± 0.47^{A}
FYM	8.61 ± 0.14^{Aa}	13.34 ± 0.40^{Ab}	12.00 ± 0.23^{Bb}	9.65 ± 0.88^{Aa}	10.90 ± 0.53^{A}
FYM + NPK	12.78 ± 0.41^{Bab}	15.57 ± 0.11^{Bc}	14.53 ± 0.10^{Cbc}	11.30 ± 1.06^{Aa}	13.55 ± 0.49^{B}
Means of the years	10.03 ± 0.60^{a}	13.82 ± 0.45^{b}	12.34 ± 0.51^{b}	9.73 ± 0.56^{a}	
ZST (mL)					
Control	16.75 ± 1.11^{Aa}	32.75 ± 2.68^{Ab}	26.75 ± 0.85^{Ab}	13.50 ± 0.29^{Aa}	22.44 ± 2.10^{A}
FYM	16.00 ± 0.91^{Aa}	39.88 ± 3.14^{Ac}	31.75 ± 1.25^{Ab}	14.75 ± 0.75^{Aa}	25.59 ± 2.86^{A}
FYM + NPK	33.00 ± 1.00^{Ba}	57.50 ± 0.54^{Bc}	46.75 ± 1.75^{Bb}	37.00 ± 1.47^{Ba}	43.56 ± 2.51^{B}
Means of the years	21.92 ± 2.42^{a}	43.38 ± 3.38^{b}	35.08 ± 2.66^{b}	21.75 ± 3.29^{a}	

Means with the standard error of the mean followed by the same letter (A – vertically; a – horizontally) are not significantly different at the 0.05 probability level. control – unfertilised treatment; FYM – farmyard manure; FYM + NPK – farmyard manure applied together with mineral NPK

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Table 6. The financial evaluation of application of different fertiliser treatments for different market prices. This financial analysis is based on the average grain and straw yields shown in Table 4. The market price for the straw is 20 EUR/t

	Profit per grain (EUR/ha)	Profit per straw (EUR/ha)	Production value (EUR/ha)	Gross profit per ha (EUR/ha)	Gross profit per t (EUR/t)	Zero profitability grain yield (t/ha)	Profitability (%)
Control							
160 EUR/t	864	116.2	980.2	281.5	49.1	4.08	1.6
180 EUR/t	978.8	116.2	1 094.9	396.1	69.1	3.66	2.3
200 EUR/t	1 093.3	116.2	1 209.5	510.7	89.1	3.31	2.9
FYM							
160 EUR/t	935	127.6	1 062.6	238.7	38.5	4.81	1.2
180 EUR/t	1 059.0	127.6	1 186.6	362.7	58.5	4.30	1.8
200 EUR/t	1 183.0	127.6	1 310.6	486.7	78.5	3.90	2.4
FYM + NPK							
160 EUR/t	1 393.2	161.6	1 554.8	415.4	51.3	5.94	1.5
180 EUR/t	1 555.2	161.6	1 716.8	577.4	71.3	5.38	2.0
200 EUR/t	1 717.2	161.6	1 878.8	739.4	91.3	4.91	2.6

control – unfertilised treatment; FYM – farmyard manure; FYM + NPK – farmyard manure applied together with mineral NPK

the preceding crops. At the same time, it shows that without the application of fertilisers, the standard yield per hectare can be harvested (Table 4), but of low quality (Table 5). In our case, the use of alfalfa as a preceding crop helped achieve standard yields in the control and FYM treatments. Legumes, together with root crops, are characterised as the best preceding crops to cereals (Kunzová and Hejcman 2009, 2010, Hejcman and Kunzová 2010). The significant effect of the preceding crop was also recorded by Hlisnikovský et al. (2016), who recorded lower average yield of winter wheat after potatoes (6.14 t/ha), and higher average yield after alfalfa (6.67 t/ha). Although standard yields were obtained in the control and FYM treatments, even a great preceding crop like alfalfa was not enough to meet the needs of wheat to synthesise enough proteins in grain. According to Barneix (2007), the protein synthesis in grain is source-limited and more than 50–70% of the final grain N is accumulated before flowering and later

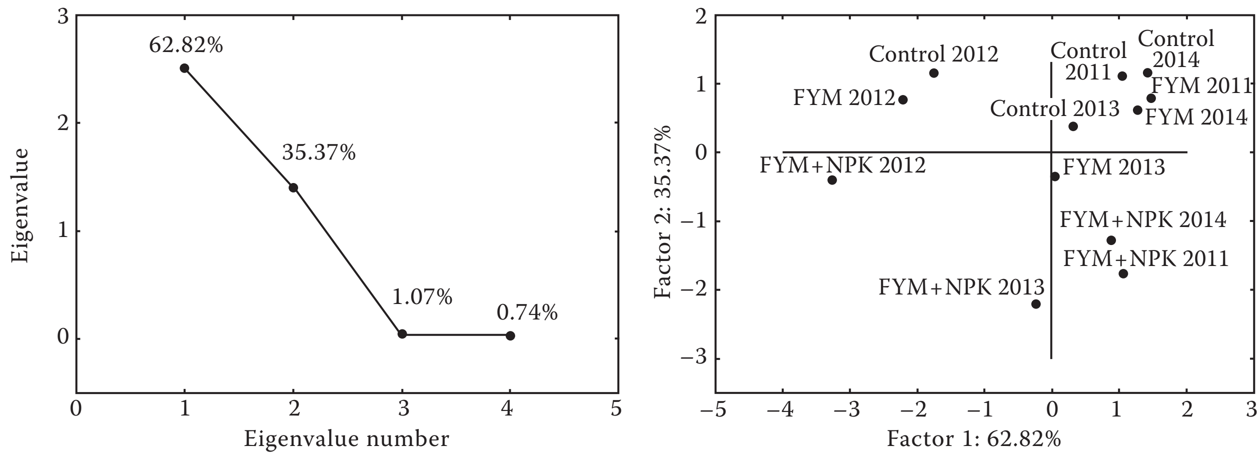

Figure 1. The eigenvalues and eigenvalues number (left) and results of the principal component analysis comparing fertiliser treatments and years (right). control – unfertilised treatment; FYM – farmyard manure; FYM + NPK – farmyard manure applied together with mineral NPK

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remobilised to the grain, where it is used for synthesis of grain proteins. While the preceding crop nutrients were utilised in the early growth stages, there was no longer any nitrogen left for protein synthesis in the control and FYM treatments, that would shift the harvested grain to higher quality classes and thus to a higher price range. The application of mineral fertilisers, which significantly and directly affected the yield and quality of wheat (Blandino and Reyneri 2009) and its root system (Rasmussen et al. 2015), and especially the qualitative fertilisation in May, helped achieve significantly higher yields and grain quality in the FYM + NPK treatment, showing an importance of mineral nitrogen for wheat in conventional agriculture.

In comparison with the FYM, the mineral fertilisers and their applications are more expensive (Table 3), but have defined composition and a rapid effect when compared with FYM. On the other hand, organic manures have inconsistent composition, affected by the source of origin (Risberg et al. 2017). The mineralisation process of the organic manures strongly depends on the environmental conditions. Under unfavourable conditions, the mineralisation process of the FYM can be completely abolished, as can be seen from the results of 2012, when grain yields varied from 2.78 t/ha to 2.86 t/ha. Such unfavourable conditions (long drought caused by an unusually warm front from the east) also significantly influenced nutrient intake from mineral fertilisers (Tables 4 and 5). Weather conditions do not only affect mineralisation and wheat yielding parameters, but also grain quality. According to Barneix (2007), more than half of the final CPC is determined by the environment. As the weather conditions adversely affected grain and straw yields in 2012, they positively influenced the CPC. The starch and protein synthesis in the grain are independent of each other and while the drought and high temperatures during the grain-filling period negatively affected the synthesis and deposition of starch (thus yields), the synthesis and deposition of proteins were not inhibited by these factors (De Stefanis et al. 2002), resulting in very high CPC in 2012, partially compensating low yields with a higher price.

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