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Soil agrochemical parameters and grain quality indices change in crop rotation

ABSTRACT. A field experiment was carried out on sandy clay loam soil of the Study and Research farm Peterlauki of the Latvia University of Agriculture (LUA). The crop rotation consists of six fields with the following crop sequence: winter wheat – winter rape – spring wheat – barley – barley + clover – clover. The experiment scheme included no fertilizer treatment and nine treatments with constant potassium, four phosphorus and three nitrogen rates, what was differentiated corresponding to the demands of the growing crops. Soil samples were taken from 0 to 20 cm depth in plots before the experiment, in the middle of crop rotation and after completion of the first rotation cycle. The aim of our study was to determine the influence of crop rotation and fertilizers on the changes of soil agrochemical properties as well as grain quality indices. The obtained data showed that the tendency of decreasing soil organic matter content by 0–6.1 g kg^{-1} on average was still observed after the completion of full rotation cycle. Research results showed insignificant increase in soil pH values connected with parent material peculiarities and high concentration of hydrogen carbonate in soil solution. Thus, acidification in topsoil was not observed even at increased doses of single superphosphate applied. There were not observed significant changes in available phosphorus (P) and potassium (K) under the influence of fertilizer during one rotation cycle. Peculiarities of meteorological conditions during the experimental years caused greater fluctuations in grain quality than the fertilizer applied.

KEY WORDS: crop rotation, fertilizers, soil agrochemical indices, gluten content, and crude protein content

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Research carried out in different soil and climatic conditions does not give a full idea of changes regarding soil agrochemical parameters or the crop yield and quality formation process. For that reason, regularities obtained as other research results are necessary to be tested in definite environment. The necessity of carrying out such studies are due to new more productive crop varieties, new fertilizers and means of plant protection coming in the production resulting in the change of mutual relationships among effecting factors and their influence on properties of the soil, the quantity and quality of the yield.

Further use of agricultural produce including grains is mainly due to quality parameters. Fertilizer, including mineral fertilizer, is one of the main crop yield formation factors along with climatic and soil conditions. Nevertheless, a response of the crop varieties to the fertilizer applied is different as various crop varieties are not capable of taking up and utilizing plant nutrients [Tatarchenko et al. 1998]. In some varieties of spring wheat Eta, Leningradka, the quality of grain gluten, irrespective of N-fertilizer rates applied, does not provide good baking quality [Ruza 1998; Zavalin et al. 1999]. Many authors are of the opinion that in winter wheat Otto [Ruza 1999; Strazdina 2001] sufficiently high rates of N-fertilizer (150-180 kg ha^{-1}) are needed for the production of high and quality grain yields. Literature findings [Volikin 1999] indicate that gluten content is more dependent on temperature than rainfall. Gluten content in grain is in direct relationship with temperature and the inverse linear relationship with rainfall. A lot of barley varieties may have a wide range of uses determined by grain quality parameters. In barley, the crude protein content in grain is of vital importance as it determines the direction of grain use [Dorbe et al. 2001].

The effect of soil agrochemical parameters on the conditions of plant growth, formation and quality of yield is most direct. Humus is one of the most important parameters having many-sided effects on properties and formation processes of soil being one of the decisive factors determining soil fertility. Intensive agricultural activity contributes to more rapid mineralization of humus resulting in the decrease of soil fertility potential. In Latvia, it has become problem of the day in fields under intensive management and rapidly decreasing organic matter incorporation into the soil during the last decade. Selection of suitable crop rotation, growing green manure crops and utilization of straw as a fertilizer are helpful in reaching non-deficit humus balance in soil [Gemste 1991; Ozeraitiene 2003]. In Latvia, agrochemical soil mapping is not done at present. Results of long-term stationary experiments allow for the estimation of the changes in these parameters. This specific crop rotation is typical of Zemgale soil climatic conditions. One of the goals of our complex research was estimation of fertilizer and definite crop rotation effect on soil agrochemical and grain quality parameters change.

METHODS

Field experiments were carried out on sandy clay loam pseudo-gley soil (Stagni-Gleyic Luvisol according to WRB, 1998) at the Study and Research farm "Peterlauki" of LUA. The experiment was established in 1997, and now full rotation cycle (winter wheat–green manure crop–spring wheat–barley–barley + clover–clover) has been completed in two of six experimental fields. Soil agrochemical parameters before the experiment were as follows: pH_{KCl} 6.6–7.5; organic matter content 35–46 g kg^{-1} of soil (Org.-C – 20.3–26.7 g kg^{-1}) (Tyurin's method), high plant available level of P (61–74 mg kg^{-1}) and K (154–219 mg kg^{-1} (Egner-Riehm DL method).

Table 1. Fertilizers applied during crop rotation

Treatment	Winter wheat			Winter rape barley + clover			Spring wheat			Spring barley			Total in crop rotation		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	kg ha^{-1}														
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	60	0	100	30	0	50	60	0	75	60	0	50	240	0	325
3	60	26	100	30	13	50	60	20	75	60	13	50	240	85	325
4	60	40	100	30	20	50	60	26	75	60	20	50	240	126	325
5	60	52	100	30	26	50	60	40	75	60	26	50	240	170	325
6	120	0	100	60	0	50	90	0	75	90	0	50	420	0	325
7	120	26	100	60	13	50	90	20	75	90	13	50	420	85	325
8	120	40	100	60	20	50	90	26	75	90	20	50	420	126	325
9	120	52	100	60	26	50	90	40	75	90	26	50	420	170	325
10	180	52	100	90	26	50	120	40	75	120	26	50	600	170	325

Full rotation cycle with the following crop sequence: winter wheat – winter rape – spring wheat – barley – barley + clover – clover was completed in 5 fields in 2002 and field 6 in 2003. Winter rape at the end of flowering was cut, chopped and incorporated into the soil as green manure. Cereal straw and clover after-grass were incorporated into the soil as well. The experiment scheme included no fertilizer treatment and nine fertilizer treatments with constant potassium, four phosphorus and three nitrogen rates, which was differentiated corresponding to the demands of the growing crops (Tab. 1). The winter cereals received N top-dressing early in spring after growth was resumed, splitting the nitrogen fertilizer doses N_{120} and N_{180} in two applications at stem elongation. The experiment was established in four replications according to standard replication method in double rows. Ammonium nitrate, single superphosphate and potassium chloride were pre-plant applied. Meteorological conditions were quite variable during the experimental years.

Samples of plants for yield chemical analysis were taken from all experimental plots. The crude protein content in grain was determined by the Kjeldahl method, multiplying the obtained nitrogen values by coefficients 6.25 and 5.7 for barley and winter wheat, respectively. Gluten content in grain was determined by Glutomatic equipment. Soil samples were collected at the beginning of each rotation prior to the sowing of winter cereals, in the middle of rotation prior to the sowing of barley, and starting a new rotation cycle prior to the sowing of winter cereals. Soil samples were taken from 0 to 20 cm depth. Changes in soil agrochemical parameters under the experimental treatments are estimated by comparing means of Paired-Samples T Test. In the experiment, reasons responsible for soil agrochemical parameters change are estimated by correlation analysis.

RESULTS

Results of six-year long research with winter wheat indicate that gluten content of grain was to a great extent influenced by meteorological conditions of a definite year (Tab. 2). Gluten content was the highest in fertilizer treatments in the years 2001 and 2003 (26.0–27.3%) and the lowest in the year 2002 (20.6–25.0%). In 1999, most expressed differentiation in gluten content depending on N-fertilizer: 24.5–25.5% and 27.2–28.3% was observed on fertilizer backgrounds N_{60} and N_{120} respectively.

The obtained mean data indicate that gluten content was influenced by N-fertilizer application, increasing N up to 120 kg ha^{-1}. Thus, for example, gluten content increased by 1.7 % with increasing N from 60 to 120 kg ha^{-1}. Applied P had a smaller effect on gluten content than applied N. Gluten content

Table 2. The effect of fertilizer on gluten content in grain of winter wheat

Treatment	Year						
	1998	1999	2000	2001	2002	2003	Mean
	%						
$N_0P_0K_0$	22.8	23.0	18.3	22.8	20.0	25.2	21.5
$N_{60}P_0K_{75}$	26.0	24.7	21.6	26.0	20.6	26.0	23.7
$N_{60}P_{26}K_{75}$	26.3	25.5	21.0	26.3	20.7	26.5	23.9
$N_{60}P_{40}K_{75}$	24.4	24.5	21.5	24.4	21.6	26.7	23.4
$N_{60}P_{52}K_{75}$	26.3	25.4	21.8	26.3	20.6	26.0	24.0
$N_{120}P_0K_{75}$	26.7	27.7	25.7	26.7	21.4	26.2	25.4
$N_{120}P_{26}K_{75}$	26.6	28.3	24.3	26.6	25.0	26.4	26.0
$N_{120}P_{40}K_{75}$	26.3	27.2	22.6	26.3	23.4	26.8	25.1
$N_{120}P_{52}K_{75}$	27.0	27.9	23.9	27.3	24.7	24.2	25.7
$N_{180}P_{52}K_{75}$	26.5	28.5	23.2	26.5	24.2	26.1	25.6

only increased with 60 kg ha^{-1} applied P on both fertilizer backgrounds ($N_{60}K_{75}$ and $N_{120}K_{75}$), respectively by 0.2 and 0.6%, but further increase in P application resulted even in a decrease. In winter wheat the mean highest gluten content 26.0% was provided by fertilizer treatment $N_{120}P_{26}K_{75}$. In the grain of winter wheat the mean values of crude protein content indicate that N rates increased up to 120 kg ha^{-1} resulted in crude protein increase by 1 per cent. The fertilizer treatment $N_{180}P_{52}K_{75}$ provided the highest crude protein yield, but crude protein increase per 1 kg NPK applied was achieved with fertilizer treatment $N_{120}P_{26}K_{75}$.

Table 3. The effect of fertilizer on gluten content in grain of spring wheat

Treatment	Year						
	1998	1999	2000	2001	2002	2003	Mean
	%						
$N_0P_0K_0$	20.6	28.0	27.8	30.1	27.0	28.8	26.9
$N_{60}P_0K_{75}$	22.8	30.4	24.6	32.2	29.1	30.3	27.9
$N_{60}P_{20}K_{75}$	25.1	30.5	30.5	32.9	29.2	29.6	29.4
$N_{60}P_{26}K_{75}$	27.4	30.6	29.1	31.8	29.6	30.3	29.6
$N_{60}P_{40}K_{75}$	25.7	31.5	30.6	31.7	28.8	29.8	29.4
$N_{90}P_0K_{75}$	26.3	31.9	30.5	33.0	29.7	31.6	30.2
$N_{90}P_{20}K_{75}$	25.5	32.0	31.7	32.5	30.0	30.7	30.2
$N_{90}P_{26}K_{75}$	25.8	30.7	30.3	32.2	30.3	31.0	29.9
$N_{90}P_{40}K_{75}$	25.0	31.1	32.2	33.4	28.8	30.0	29.8
$N_{120}P_{40}K_{75}$	26.3	29.2	31.8	33.9	30.0	31.3	30.3

In six experimental years, gluten content (Tab. 3) in spring wheat grain was the highest in fertilizer treatments in 2001 (32.1–33.9%), and the lowest in 1998 (22.8–27.4%). In the other experimental years these changes were very similar. The obtained mean data show that gluten content was the greatest with N-fertilizer, however more expressed tendencies were observed with the increase of N rate up to 90 kg ha^{-1}. Further increase in N rate up to 120 kg ha^{-1} did not result in increased gluten content in grain. Fertilizer P exhibited a small effect on gluten content, and it was observed using N rate 60 kg ha^{-1} but at N application rate 90 kg ha^{-1} even showed a decrease. In spring wheat grain, the highest gluten content 30.2 % was provided by fertilizer treatment $N_{90}P_{20}K_{75}$. In spring wheat, N fertilizer application had a smaller effect on the yield of grain. Practically there were not observed any fluctuations in crude protein content between the fertilized treatments. The application of $N_{120}P_{40}K_{75}$ provided the highest crude protein yield, but the greatest yield increase per 1 kg NPK applied was achieved with fertilizer treatment $N_{90}P_{26}K_{75}$. In winter and spring wheat, P-fertilizer application did not affect crude protein content in grain.

Table 4. The effect of fertilizer on crude protein content in grain of spring barley

Treatment	Year					
	1999	2000	2001	2002	2003	Mean
	%					
$N_0P_0K_0$	13.2	13.4	14.6	12.1	12.6	13.1
$N_{60}P_0K_{50}$	14.3	14.5	15.0	12.8	13.5	13.9
$N_{60}P_{13}K_{50}$	14.6	14.7	15.3	12.8	13.0	13.9
$N_{60}P_{20}K_{50}$	14.2	14.4	15.3	12.7	12.9	13.7
$N_{60}P_{26}K_{50}$	14.1	14.6	15.2	12.7	12.8	13.7
$N_{90}P_0K_{50}$	14.9	15.1	16.1	13.5	13.9	14.6
$N_{90}P_{13}K_{50}$	15.1	15.0	16.3	13.6	13.9	14.6
$N_{90}P_{20}K_{50}$	14.9	14.9	16.1	13.7	13.9	14.6
$N_{90}P_{26}K_{50}$	15.1	15.1	15.9	13.7	13.6	14.5
$N_{120}P_{26}K_{50}$	15.3	15.3	16.3	14.1	14.6	15.0

Five-year long experiments with spring barley show that the crude protein content was affected by meteorological conditions of a definite experimental year (Tab. 4). The highest content of crude protein was reached in 2001 (14.6–16.3%), but the lowest in 2002 (12.1–14.1%). The crude protein content increased with increasing rates of applied N as observed in all experimental years and approved by the obtained mean results. It should be emphasized that fertilizer treatments with N rate 60 kg ha^{-1} significantly dropped behind the treatments with the applied N rates 90 and 120 kg ha^{-1} regarding crude protein content. The crude protein content did not increase under the influence of applied P at the rate on both fertilizer backgrounds ($N_{60}K_{50}$ and $N_{90}K_{50}$). Further increase in P rate resulted in the decrease of crude protein content. In spring barley, the mean highest crude protein content 15.1 % was provided with the fertilizer treatment $N_{120}P_{26}K_{50}$.

Results of two-factorial dispersion analysis show that both factors "fertilizer" and "year" have significantly influenced gluten content in the grain of winter wheat (P = 0.000; F = 8.734) and spring wheat (P = 0.000; F = 0.196), the corresponding criteria of which were P = 0.000; F = 32.870 for winter wheat and P = 0.000; F = 50.738 for spring wheat. However, significant differences in gluten content were only stated between unfertilised treatment and treatments receiving fertilizer. Factors "year" and "fertilizer" exerted a similar effect on crude protein content in barley grain.

Correlation analysis shows that the increase of total produced yield decreased the crude protein content in winter wheat (r = -0.410; P = 0.000) and spring barley (r = -0.378; P = 0.007), as well as gluten content in winter wheat (r = -0.384; P = 0.002). Peculiarities of meteorological conditions during the experimental years caused greater fluctuations in quality parameters of all the studied cereals than the applied fertilizer. Soil humus in fields is one of most dynamic components of soil under the conditions of intensive farming. Its dynamics is to a great extent dependent both on the total amount and composition of plant residues mass got into the soil, C to N ratio in plant residues mass as well as N balance in the corresponding field. Hence, all these variables can vary in a rather wide range not only depending on the fertilizer but meteorological conditions of a definite year as well, regularities in the change of total humus content under the influence of applied fertilizer scheme are frequently hard to be noticed.

In our experiment, crop rotation fields which have completed full rotation cycle showed rather different changes in humus content during six experimental years. These changes in experimental field 5 varied on average from + 0.1 to – 6.3 g kg^{-1}, but in field 6 from + 0.1 to – 8.0 g kg^{-1} on average. Strongly negative humus balance was observed in treatments with the least plant residues masses incorporated into soil as well as in treatments with a strongly positive N balance. Statistically significant changes in humus content at the result of full rotation cycle realization were observed only in field 5 in the second ($t_{0.05}$ = 7.649; P = 0.005) and third ($t_{0.05}$ = 3.525; P = 0.039) experiment treatments with the least recorded incorporated total mass of plant residues found in the fertilized treatments as well as in treatment ten ($t_{0.05}$ = 3.266; P = 0.047), where N-fertilizer showed very low efficiency, but where positive N balance was the strongest. A significant effect of variables effecting particular humus content dynamics on humus content changes as the result of full rotation cycle was not observed. Close negative correlation r = -0.710 (P = 0.000) within humus content changes is shown by humus content in soil at the beginning of rotation. In field 5, correlation coefficient is r = -0.852 (P = 0.002), but in field 6 – r = -0.803 (P = 0.005).

Table 5. Change in humus content in soil, ± g kg^{-1}

Treatment	First link of crop rotation			Second link of crop rotation	
	field 5	field 6	field 1	field 5	field 6
1	-2.5	2.9	-1.1	0.0	-5.4
2	-4.4	-2.3	-1.0	-2.5	-0.2
3	-3.3	-1.2	-0.9	-0.1	1.4
4	-0.3	2.1	-0.1	0.2	-3.5
5	2.1	0.5	3.8	1.7	-4.2
6	-3.3	-6.1	-0.6	1.1	-2.0
7	-4.6	0.1	0.4	5.2	-0.6
8	-3.6	0.9	0.9	4.7	-3.8
9	3.2	-3.5	0.7	-1.4	-0.6
10	-5.1	-2.0	-1.2	1.1	0.1

Table 6. Incorporated plant residue mass and N balance in first rotation cycle

Treat-ment	Winter wheat				Rape		Spring wheat				Total plant residue DM t ha^{-1}		3-year total N balance kg ha^{-1}	
	straw yield t ha^{-1}		N balance kg ha^{-1}		DM of green mass t ha^{-1}		straw yield t ha^{-1}		N balance kg ha^{-1}					
	Field													
	5	6	5	6	5	6	5	6	5	6	5	6	5	6
1	2.40	5.15	-52	-65	4.05	5.34	2.96	4.21	-72	-91	8.66	13.39	-124	-155
2	4.45	7.51	-35	-33	4.59	6.29	3.50	4.09	-28	-50	11.42	16.26	-33	-53
3	4.10	6.70	-33	-43	4.45	6.79	3.51	4.45	-33	-61	11.00	16.39	-37	-74
4	4.15	7.46	-29	-49	4.84	7.64	3.46	4.74	-31	-66	11.39	18.13	-30	-86
5	4.19	7.75	-32	-55	5.33	7.95	3.36	4.77	-33	-66	11.82	18.72	-35	-92
6	4.12	7.06	31	10	5.84	6.32	3.65	4.58	-5	-34	12.53	16.32	86	36
7	4.19	6.68	25	-9	5.34	6.83	3.60	4.73	-7	-41	12.04	16.65	79	10
8	4.32	6.68	30	-10	5.63	7.16	3.61	4.90	-6	-44	12.44	17.11	84	7
9	3.86	6.45	29	-13	5.95	7.11	3.56	4.89	-6	-46	12.33	16.86	83	1
10	4.14	7.74	83	29	7.01	8.12	3.95	5.21	19	-24	13.97	19.26	192	95

Table 7. Incorporated plant residue mass and N balance in second rotation cycle

Treat-ment	Spring barley				Spring barley + clover				Clover		Total plant residue DM t ha^{-1}		4- and 5-year total N balance kg ha^{-1}	
	straw yield t ha^{-1}		N balance kg ha^{-1}		straw yield t ha^{-1}		N balance kg ha^{-1}		after grass DM t ha^{-1}					
	Field													
	5	6	5	6	5	6	5	6	5	6	5	6	5	6
1	2.96	3.12	-79	-61	3.14	2.24	-60	-59	4.75	3.63	10.00	8.23	-139	-120
2	4.16	4.31	-38	-8	3.72	3.35	-45	-60	4.67	3.50	11.45	10.09	-84	-68
3	4.00	4.56	-44	-13	4.41	3.72	-51	-67	4.73	3.45	11.96	10.57	-95	-80
4	3.95	4.66	-46	-15	4.35	3.63	-48	-63	4.80	3.48	11.94	10.61	-94	-78
5	3.97	4.56	-46	-14	4.89	3.70	-51	-62	5.10	3.42	12.72	10.52	-97	-77
6	4.23	5.02	-18	7	4.92	3.48	-22	-35	5.18	3.25	13.05	10.56	-40	-28
7	4.64	5.31	-22	4	5.40	3.94	-25	-38	5.25	3.30	13.88	11.26	-48	-34
8	4.72	5.62	-26	4	5.43	4.12	-26	-40	5.30	3.30	14.03	11.68	-53	-36
9	4.58	5.30	-28	5	5.56	4.25	-27	-39	5.27	3.38	13.99	11.59	-55	-35
10	4.72	5.51	-3	31	5.41	4.37	-3	-13	5.20	3.40	13.92	11.90	-6	17

With the aim of investigating green manure effect in crop rotation, soil samples were collected in the middle of rotation – in autumn of the third experimental year. Dynamics of humus content in different experimental fields as shown in Table 5 was rather different in various crop rotation links. As shown in Tables 6 and 7, not uniform distribution of plant residues masses and plant residues composition in time and space were the main reasons for differences. In rotation field 5, reduction in humus content was observed in the first rotation link mainly due to the low efficiency of nitrogen applied, most positive balance of this element in winter wheat sowing. In field 6, the greatest reduction in humus content was observed in rotation second link. It could be explained by a comparatively lower level of plant residues output during the last years of rotation and non-effective N consumption by plants in spring barley sowing. In the first crop rotation link, the greatest effect on humus content changes was exerted by N content in winter wheat straw: r=-0.572 (P=0.008). Besides, in field 6 this effect was particularly strong – r=-0.855 (P=0.002). A significant effect on changes in humus content in this crop rotation link was exerted by N balance in winter wheat (r=-0.450; P=0.046) and spring wheat (r=-0.463; P=0.040) sowings. In field 6, change of these factors and humus content correlation coefficients accounted for r=-0.648 (P=0.043) and r=-0.686 (P=0.023), respectively.

More effective N use was observed in barley grown in the second link of crop rotation than in wheat grown in the beginning of rotation. With this, in this crop rotation link changes in humus content were much more than previously affected by the mass of plant residues grown concluding the crop rotation. Thus, in the fifth crop rotation year, straw mass of spring barley grown with intercrop clover with change in humus content shows correlation coefficient r = 0.680 (P = 0.001).

In the experiment the results lead to the conclusion that the observed mean tendency of the increase of available P content in soil along with the increase in P rates applied is not statistically proved as great differences were observed in the change of available P content between replications of the experiment.

During crop rotation cycle, equal rates of K-fertilizer were applied in all the fertilized treatments. The reasons for changes in this plant nutrient content could be explained by the difference in the off-take by crop yield, green manure effect as well as partly changes in the availability of this element under the influence of meteorological conditions (more prolonged periods of drought). In fields with completed full crop rotation cycle, there were not observed any significant changes in available K content in soil. During the first half of rotation, in field 6 there was observed a significant increase in K content in treatments 8 ($t_{0.05}$=3.880; P = 0.030), 9 ($t_{0.05}$ = 28.868; P = 0.000) and 10 ($t_{0.05}$ = 10.392; P = 0.002), which was caused by high fixed K content in the green mass of rape: 452, 431 and 537 kg ha^{-1} K in treatments 8, 9, and 10, respectively. In field 5, in the above mentioned treatments, the observed amount of the accumulated K in rape green mass dry matter was less by 10–60 kg ha^{-1} as the result of which the increase in available K content after the first half of rotation does not exceed the level of significance.

CONCLUSIONS

1. Research results suggest that the nitrogen fertilizer exerts an effect on grain quality parameters, yet in well-cultivated soils the effect of meteorological conditions of a definite year is even greater.

2. In winter wheat, gluten content in grain is the highest with the fertilizer rate $N_{120}P_{60}K_{90}$ but in spring wheat with N_{90} $P_{45}K_{90}$. The positive effect of N-fertilizer on crude protein content in grain is observed in winter wheat and spring barley.

3. In spring barley, increased crude protein content in grain dry matter shows that cv. "Malva" is not suitable as brewer′s barley when grown on high agricultural background.

4. In the studied cereal rotation, incorporation of dry matter mass of crop residues, green manure and clover after-grass into soil only in particular treatments provide the maintenance of organic matter content at its initial level, while in other treatments the decrease is observed.

5. The change of soil pH values indicates that acidification during rotation cycle as well as significant fluctuations in P and K content are not observed in any of the fertilized treatments.

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