OPTIMIZATION OF TECHNOLOGICAL MEASURES TO PROMOTE CEREAL STRAW DECOMPOSITION IN THE POST HARVEST PERIOD

Ausra Arlauskiene, Aleksandras Velykis, Alvyra Slepetiene
Lithuanian Research Centre for Agriculture and Forestry
arlauskiene.ausra@gmail.com

Abstract. Investigations of post harvest technological measures for promotion of initial winter wheat straw decomposition were carried out over the period 2008-2011 in the model field experiments at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry. Measures used for straw decomposition: 1) stubble cultivation at 10 cm depth, straw removed from the field, 2) nitrogen fertilizer use on non-incorporated straw, 3) nitrogen fertilizer use with straw incorporation during stubble cultivation, 4) slurry use with straw incorporation during stubble cultivation. Changes in dry matter, carbon, nitrogen, phosphorus and potassium were observed at 9 months after incorporation the straw. Straw decomposition was slowest when straw was spread on the surface with N fertilizer without incorporation into the soil. DM content in the straw decreased similarly when it was incorporated with N fertilizer or with slurry. C decreased by 15.5 % in straw incorporated only with the stubble cultivator and with N fertilizer – 20.4 % compared with the former quantity. C:N decreased from 100 to 43 in straw, when it was incorporated together with N fertilizer. This affected higher mineral nitrogen $N_{min.}$ of soil by 10.3 % in spring if compared to the plot without straw.

Keywords: cereal straw, technological measure, decomposition.

Introduction

Cereal straw is of renewed interest as a potential source of bioenergy. However, the sustainability of this practice which implies systematic removal of aerial biomass of cereal crops is a controversial issue, particularly in soils having a low soil organic carbon (SOC) content [1]. Straw is natural organic manure that is decomposed by microorganisms of the soil and transformed into other organic compounds. The primary division of straw or N immobilisation is affected by a wide C and N ratio in straw [2]. In order to make the decomposition of straw more rapid and to increase N immobilisation to the biomass of microorganisms and organic compounds of soil, it is necessary to incorporate additional nitrogen fertilizer, to increase the contact with the soil microorganisms, the soil moisture and nutrients [3]. It was defined that upon incorporation straw of crops to the soil and nitrogen fertilizer increases the activeness of microorganisms, carbon and nitrogen content in their biomass while in soil – the content of easily assimilative organic compounds; humus destruction reduces together with leaching of nitrogen. Incorporation of straw into soil can be a strong means for controlling N dynamics in soil and reduces the leaching of N fertilizer, because straw will enhance microbial N immobilization due to the high C:N ratio of the materials [2]. Later, upon decomposition of straw, nitrogen has a low effect on the decomposition of the straw mass. Then organic compounds that are difficult to decompose (lignin) are decomposed and transformed [4]. The degradation of organic macromolecules, including lignin, in plant-derived soil organic matter, is important to the global carbon cycle. When straw is applied for manure, the humus content in the soil is increased as well as the physical and chemical properties [5]. Therefore, practice of appropriate application of straw for manure may complement to the restoration and increase of the soil fertility [6]. The aim of the experiments was to define the effect of different technological measures on the intensity of decomposition of winter wheat straw on the primary stage as well as peculiarities of emission of biological elements.

Materials and methods

Experimental site and soil. The research was done in the northern part of Central Lithuania lowland (56º12’ N, 24º20’ E). The soil of the experimental site is *Endocalcari – Endohypogleyic Cambisol (CMg-n-w-can).* The soil texture is clay loam on silty clay with deeper lying sandy loam. The topsoil is close to neutral, medium in phosphorus (P_2O_5 146-169 $mg \cdot kg^{-1}$ soil), high in potassium (K_2O 221-260 $mg \cdot kg^{-1}$ soil) and moderate in organic carbon 1.50 %.

Three analogous field experiments were carried out. The experiments were organised after the winter wheat harvesting in different periods: 2008-2009 (I experiment), 2009-2010 (II experiment) and 2010-2011 (III experiment). Stimulation of decomposition of straw of winter wheat was affected by the following measures: 1) stubble cultivation at 10 cm depth, straw removed from the field (control treatment) (SC); 2) nitrogen fertilizer spread on non-incorporated straw (N); 3) nitrogen fertilizer spread and straw incorporation during stubble cultivation (N+SC); 4) animal slurry spread and straw incorporation during stubble cultivation (S+SC). Nitrogen fertilizer (norm 1t of straw N 10 kg) in fields of 2 and 3 treatments was spread in the form of urea.

The slurry content in fields of the 4th treatment was calculated according to the nitrogen content required for the decomposition of straw. On the second half of October the experiment field was ploughed. Straw was incorporated by the universal stubble cultivator SL-2.5, composed from double sagittal shares, one line of discs and crumbling rollers. The spring barley cultivar Luoke was grown the next year under the ordinary intensive technology. For the assessment of the changes of the chemical content, the samples of the cut straw with identification of the dry matters (DM) content, concentrations of carbon (C), nitrogen (N), phosphorus (P) and potassium (K), were inserted into cellular polychlorvinyl bags (straw was also incorporated into the field of the control treatment). For assessment of the decomposition process, the bags with residues of straw were considered 9 months after the incorporation. Straw of winter wheat was analysed for C (Dumas method), N (Kjeldahl method), P and K (using spectrophotometer UV/VIS Cary 50 and atomic absorptiometer AANALYST 200 respectively). The mineral nitrogen ($N_{min.}$) content in the 0-60 cm soil layer was measured in the second year – in the spring ($N\text{-}NO_3$ by ionometric and $N\text{-}NH_4$ by spectrophotometric methods). Decomposition efficiency according to the changes of straw DM mass (E_M) and carbon (Ec) were calculated under formulas (1 and 2):

$$E_M = \left(\frac{M_{start} - M_{end}}{M_{start}} \right) \cdot 100, \tag{1}$$

$$E_C = \left(\frac{C_{start} - C_{end}}{C_{start}} \right) \cdot 100, \tag{2}$$

where M_{start} and C_{start} – mass of dry matter of straw (g) and C (g·kg^{-1} DM) prior application for manure;
M_{end} and C_{end} – mass of dry matter of straw (g) and C (g·kg^{-1} DM) at the end of the experiment.

Meteorological conditions. The period of 2008 after harvesting of crops was characterised by a greater precipitation rate at the beginning of the straw decomposition. In July the precipitation rate was 48.6 mm higher if compared to the long-term average data. The autumn was several degrees warmer than usually. Average negative day temperature became constant on the second decade of December. The winter in 2008-2009 was cold and snowy. The spring (March) started with warmer and wetter weather. The positive average day temperature was fixed during the last days of March.

In August – November 2009 the precipitation rate was close to the long-term average. The greater average day temperature was in September and in November. Average negative day temperature became constant of the second decade of December. Winter of 2009-2010 was colder if compared to the long-term average data. Positive average day temperature was fixed in the middle of March.

In 2010 after warm and averagely wet August, in September – October rather dry as well as cold weather was observed (precipitation rate was half of an average monthly rate). Winter weather started on the last days of November. Winter in 2010-2011 was changeable. Warm weather (positive daily temperature) was observed since the beginning of April. The research data were processed by the one-factor analysis of variance (ANOVA version 3.1, 2000).

Results and discussion

After application of straw for manure, the high content of dry organic matter 3.88-4.57 t·ha^{-1}, carbon – 1707-2267 kg·ha^{-1} and potassium – 22-53 kg·ha^{-1} was incorporated to the soil. Significantly lower content of nitrogen and phosphorus (respectively 16-28 kg·ha^{-1} and 2-5 kg·ha^{-1}) was incorporated into the soil with straw. Such chemical content of straw determined wide C and N as well as C and P ratio (C:N = 81-111; C:P = 481-760) as well as their division peculiarities.

9 months after the incorporation of straw, i.e., at the beginning of the next period of vegetation, the DM content in straw reduced averagely from 849 $g \cdot kg^{-1}$ to 329 $g \cdot kg^{-1}$. During the first stage of decomposition of residues of plants the water soluble, easily accessible organic compounds were decomposed. Water-soluble compounds in the residues appear to be particularly important for the high microbial activity in the initial phase, the microbiologic activeness increases [7]. Decomposition efficiency of straw (E_M) was averagely 61.3 % (Table 1). E_M was dependent upon meteorological conditions during the primary stage of the decomposition of straw as well as from duration of the positive temperature period during autumn-winter-spring (March, April). Straw was the most intensively decomposed during the II experiment (E_M = averagely 73.8 %), while the slowest decomposition – during the III experiment (E_M = averagely 49.6 %). According to average data, significantly lower E_M of straw was without its incorporation, but leaving it on the soil surface (E_M = 57.7 %), while significantly higher – when the decomposition of straw was implemented by measures of mineral nitrogen fertilizer or slurry and straw, incorporated with the stubble cultivator (respectively E_M = 63.0 % and E_M = 63.9 %), if compared to the control treatment.

Residues of plants, as the nutrient and the source of energy, serve for the restoration of the soil fertility, increase of the productivity of crops and can be characterised not only by a short term, but also by the long term effect. During the experiment I the efficiency of decomposition of carbon compounds (E_C) was averagely 13.7 %, II – 23.5 % and during III experiment – 10.0 % (Table 1). The most rapid decomposition was observed in straw that was incorporated into the soil by the stubble cultivator with nitrogen fertilizer or the animal slurry (E_C respectively 20.4 and 18.6 %), the slowest – straw, spread on the soil surface (+N manure) and incorporated only during the autumn ploughing (E_C = 7.1 %). Moreover, straw incorporated by the stubble cultivator (without nitrogen fertilizer) to the upper layer of the soil was decomposed two times faster (E_C = 15.5 %), if compared to the straw spread on the soil surface with nitrogen fertilizer and incorporated only during the autumn ploughing.

Table 1

Decomposition efficiency of straw applied for the manure

Technological measures	Decomposition efficiency (E_M)				Decomposition efficiency (E_C)			
	Experiment			Mean	Experiment			Mean
	I	II	III		I	II	III	
SC	60.1	72.7	48.6	60.5	19.7	23.6	3.2	15.5
N	56.5	70.9	45.8	57.7	0	18.9	6.5	7.1
N+SC	62.1	75.6	51.4	63.0	20.3	25.5	15.6	20.4
S+SC	63.6	75.8	52.4	63.9	14.9	26.1	14.8	18.6
Mean	60.6	73.8	49.6	61.3	13.7	23.5	10.0	15.4
LSD_{05}	2.89	1.61	3.61	1.49	10.99	9.32	8.33	4.33

Note: SC – stubble cultivation, straw removed from the field (control treatment); N – nitrogen fertilizer use on non-incorporated straw; N+SC – nitrogen fertilizer use with straw incorporation during stubble cultivation; S+SC – slurry use with straw incorporation during stubble cultivation.

The greatest part of the crop straw (~80 %) is composed from non-nitrogen organic compounds – hemicelluloses, celluloses and lignin [8]. Straw has a low amount of nitrogen and phosphorus and they are the most often included into the content of organic compounds, resistant for the decomposition. Therefore, upon rapid decrease of straw DM, C content, N and P concentrations in dry matters increased. 9 months after the incorporation of straw the mostly N concentration increased during the experiment I – 2.2 times, while during II and III – less, respectively 1.1 and 1.7 times if compared to the previous one before their application for manure (Table 2). Comparing the measures applied for the decomposition of straw, it was defined that the most increase of N concentration (averagely 29.5 %) was observed when straw was incorporated with the stubble cultivator with nitrogen fertilizer if compared to the cases when straw was incorporated by the stubble cultivation only. During this period the soil microorganisms used N from mineral fertilizers for the decomposition – immobilisation of N was taking place. According to O. B. Орлова [9], microorganisms include up to 13 % of the N content used for the manure into the own biomass and up to 57 % of N into the content of the organic compounds of soil. The lower N immobilisation was observed when straw was spread on the soil surface with N fertilizer (data from II and III experiments). This happens due to a weak contact of microorganisms with straw and nitrogen. If straw is incorporated late in autumn during ploughing, the low temperature limits microbe N immobilisation and N losses are possible. The higher gross mineralisation observed in straw-amended soil cannot be explained only by the mineralisation and release in soil of straw-derived N and may be due, after incorporation of straw, to extra mineralisation of soil organic matter and, later on, to remineralisation of previously immobilised N [8].

During the experiments, implemented in different years, straw differed by the chemical content, therefore, during the period of the experiment C:N in straw in I and III experiments was reduced from 109:1 and 111:1 and respectively to 32-52 and 49-76:1 and in II experiment – from 81:1 to 41-94:1 (Table 2). In all experiments significantly lower C and N ration was determined by straw incorporated together with mineral N fertiliser by stubble cultivation. The highest C:N (averagely 72) remained when straw (+N fertilizer) was spread on the soil surface and incorporated only during the autumn ploughing. The latter was not observed during the year when at the beginning of the straw decomposition the excessive precipitation rate was observed (I experiment). According to the data of many researchers, N immobilisation is not happening when C:N reaches 25-30. Literature indicates that microbiological processes are taking place the most intensively in soil during the first – second week after straw incorporation. The relatively rapid N loss during this period, suggested that low temperatures restricted microbial N immobilization more than it did gross decomposition [7]. Moreover, at the end of summer there is a sufficient amount of warmth and moisture observed, therefore the microbiological activeness is the most intensive [10].

Table 2

Change of nitrogen and nitrogen and carbon ratio upon application of various measures for stimulation of decomposition of straw

Technological measures	Nitrogen, % from the initial content				C:N			
	Experiment			Mean	Experiment			Mean
	I	II	III		I	II	III	
SC	189.5	91.5	168.7	149.9	46	68	63	59
N	242.4	72.1	136.5	150.3	47	94	75	72
N+SC	225.0	150.1	188.6	187.9	39	41	49	43
S+SC	203.9	114.1	173.3	163.8	45	53	54	51
Mean	215.2	109.8	168.6	165.9	44	64	60	56
LSD_{05}	16.78	15.32	19.98	14.78	5.4	16.2	11.0	15.3

Note: SC – stubble cultivation, straw removed from the field (control treatment); N – nitrogen fertilizer use on non-incorporated straw; N+SC – nitrogen fertilizer use with straw incorporation during stubble cultivation; S+SC – slurry use with straw incorporation during stubble cultivation.

Phosphorus concentration in straw increased, but not as significantly as N (averagely 1.3 times if compared to the one prior application for manure) (Table 3). In separate elements P changes were unambiguous. P concentration increased the most when straw was applied for manure together with N fertilizer or slurry and incorporation by a stubble cultivator while the lowest – when straw was spread on the soil surface (+N fertilizer) (differences in II and III experiments were significant).

Crops accumulate more potassium in straw if compared to grains. K is found in the plant mineral compounds. Differently from N and P, averagely 40.9 % of K was reduced from straw during the first 9 months after their application for manure (Table 3). The most reduction of the potassium content (averagely 53.3 %) was observed in straw that was spread on the soil surface in autumn and incorporated during the autumn ploughing.

Mineral nitrogen content of soil is mostly used as the indicator of N accessibility for plants. $N_{min.}$ can increase after manure with straw because of mineralisation of organic matters of the soil or remineralisation of the immobilised N, but not because of N reduction upon decomposition of straw. The higher gross mineralisation observed in straw-amended soil cannot be explained only by the mineralisation and release in soil of straw-derived N and may be due, after incorporation of straw, to extra mineralisation of soil organic matter and, later on, to remineralisation of previously immobilised N [11].

Table 3

Phosphorus and potassium changes upon application of various measures for stimulation of straw decomposition

Technological measures	Phosphorus, % from the initial content				Potassium, % from the initial content			
	Experiment			Mean	Experiment			Mean
	I	II	III		I	II	III	
SC	177.2	61.3	136.5	125.0	82.9	31.4	71.5	62.0
N	201.3	42.6	105.2	116.4	59.5	14.0	66.5	46.7
N+SC	188.4	83.0	139.3	136.9	77.0	32.9	84.0	64.7
S+SC	188.8	76.5	143.7	136.3	81.8	30.5	76.0	62.8
Mean	188.9	65.9	131.2	128.7	75.3	27.2	74.5	59.1
LSD_{05}	26.98	8.40	18.14	12.94	13.14	10.34	24.93	9.86

Note: SC – stubble cultivation, straw removed from the field (control treatment); N – nitrogen fertilizer use on non-incorporated straw; N+SC – nitrogen fertilizer use with straw incorporation during stubble cultivation; S+SC – slurry use with straw incorporation during stubble cultivation.

9 months after the straw incorporation, at the beginning of the other period of vegetation, the effect of the analysed measures of mineral nitrogen content in the 0-60 cm layer of the soil was determined (Table 4).

Table 4

Mineral nitrogen content in soil (0-60 cm) after application of various measures for stimulation of straw decomposition

Technological measures	$N_{min.}$				NO_3/NH_4			
	Experiment			Mean	Experiment			Mean
	I	II	III		I	II	III	
	$Mg \cdot kg^{-1}$ of soil							
SC	5.72	3.27	6.44	5.14	2.04	1.04	2.26	1.78
N	6.43	3.07	5.75	5.08	2.39	0.89	1.96	1.75
N+SC	6.19	3.46	7.37	5.67	2.35	1.17	2.74	2.09
S+SC	5.01	3.29	6.57	4.96	1.63	1.08	2.34	1.68
Mean	5.84	3.27	6.53	5.21	2.10	1.05	2.33	1.83
LSD_{05}	0.723	0.440	1.148	0.680	0.702	0.293	0.639	0.360

Note: SC – stubble cultivation, straw removed from the field (control treatment); N – nitrogen fertilizer use on non-incorporated straw; N+SC – nitrogen fertilizer use with straw incorporation during stubble cultivation; S+SC – slurry use with straw incorporation during stubble cultivation.

According to the average data of three experiments, in spring the highest $N_{min.}$ content was observed with straw incorporated by the stubble cultivator with N fertilizer. Here $N_{min.}$ increased averagely by 10.3 % (in III experiment – significantly 14.4 % if compared to the soil without manure by straw). In this partially decomposed straw C:N was 43 and this indicates that N immobilization was still happening. However, mineralization of immobilized N (re-mineralization) was more intense. This is indicated by the increased $N_{min.}$ content in soil. $N_{min.}$ had a tendency to decline – N immobilisation was stronger if compared to remineralisation in two experiments from three, when straw was spread on the soil surface (+N fertilizer) and incorporated only during the autumn ploughing. With the increasing content of $N_{min.,}$ the nitrate part of N also increased.

Conclusions

1. The most intensive decomposition was observed in straw, incorporated into the soil with mineral N fertilizer or slurry. Here the intensity of straw decomposition according to the mass (EM) was respectively 63.0 and 63.9 % and according to the carbon content (EC) respectively 20.4 and 18.6 %. The lower decomposition of straw was observed with straw spread on the soil surface (+N fertilizer) and incorporated during the autumn ploughing. The C content of straw, incorporated by a stubble cultivator (without N fertilizer) to the upper soil layer reduced more (15.5 %) if compared to straw spread on the soil surface with N fertilizer (7.1 %).

2. When straw is spread on the soil surface the soil microorganisms are not offered conditions to contact with straw and nitrogen which is necessary for the decomposition. Therefore, in spring the straw includes rather high C:N = 72 and this increases the immobilisation of mobile N from the soil during the period of vegetation.
3. During primary stages of straw decomposition N, P and K release from straw depends not only on the intensity of decomposition, but on their form in straw. Increase of N and P concentrations in straw was mainly affected by the reduced DM content. During the primary decomposition of straw, averagely 40.9 % of K is released. This process is more intense after spreading straw on the soil surface without incorporation after the harvesting of crops.
4. Incorporation of straw by a stubble cultivator after the harvesting of crops together with mineral N fertilizer determined Nmin. content, higher by 10.3 % if compared to the field without straw. This indicates that upon application of this technological measure, N remineralisation was more intense than immobilisation and there will be no negative effect of straw decomposition after their incorporation for the cultivated crops.

References

1. Powlson D.S., Riche A.B., Coleman K. etc. Carbon sequestration in European soils through straw incorporation: Limitations and alternatives. Waste Management, vol. 28, 2008, pp. 741-746.
2. Shindo H., Nishio T. Immobilization and remineralization of N following addition of wheat straw into soil: determination of gross N transformation rates by ^{15}N-ammonium isotope dilution technique. Soil Biology & Biochemistry, vol. 37, 2005, pp. 425-432.
3. Wiedow D., Baum Ch., Leinweber P. Inoculation with Trichoderma saturnisporum accelerates wheat straw decomposition on soil. Archives of Agronomy and Soil Science, vol. 53 (1), pp. 1-12.
4. Kabuyah R.N.T.M, Van Dongen B.E., Bewsher A.D. etc. Decomposition of lignin in wheat straw in a sand-dune grassland. Soil Biology & Biochemistry, vol. 45, 2012, pp. 128-131.
5. Le Guillou C., Angers D.A., Leterme P. etc. Differential and successive effects of residue quality and soil mineral N on water-stable aggregation during crop residue decomposition. Soil Biology & Biochemistry, vol. 43, 2011, pp. 1955-1960.
6. Van Groenigen K.J., Hastings A., Dermot Forristal D. etc. Soil C storage as affected by tillage and straw management: An assessment using field measurements and model predictions. Agriculture, Ecosystems and Environment, vol. 140, 2011, pp. 218-225.
7. Marschner P., Umar S., Baumann K. The microbial community composition changes rapidly in the early stages of decomposition of wheat residue. Soil Biology and Biochemistry, vol. 43 (2), 2011, pp. 445-451.
8. Henriksen T.M., Breland T.A. Nitrogen availability effects on carbon mineralization, fungal and bacterial growth, and enzyme activities during decomposition of wheat straw in soil. Soil Biology & Biochemistry, vol. 31, 1999, pp. 1121-1034.
9. Орлова О.В. Активное органическое вещество как регулятор процессов трансформации азота и углерода в дерного-подзолистых почвах. Автореферат диссертации на соискание ученой степени доктора биологических наук. Санкт-Петербург, 2013. 48 с.
10. Baumann K., Marschner P., Smernik R.J. etc. Residue chemistry and microbial community structure during decomposition of eucalypt, wheat and vetch residues. Soil Biology & Biochemistry, vol. 41, 2009, pp. 1966-1975.
11. Recous S., Aita C., Mary B. In situ changes in gross N transformations in bare soil after addition of straw. Soil Biology & Biochemistry, vol. 31, 1999, pp. 119-133.