doi: 10.17221/32/2015-SWR

Response of Organic Nitrogen in Black Soil to Long-term Different Fertilization and Tillage Practices in Northeast China

Li YAN[1,2], *Hui LI*[1,3], *Jinjing ZHANG*[1], *Zhidan ZHANG*[1], *Ping ZHU*[4], *Qiang GAO*[1]
and Wenxi LU[2]

[1]*College of Resource and Environmental Science, Jilin Agricultural University, Changchun, P.R. China;* [2]*Key Laboratory of Groundwater Resources and Environment, Ministry of Education, Jilin University, Changchun, P.R. China;* [3]*Inner Mongolia Herba Cistanches Biotechnology Co., Ltd, Changchun, P.R. China;* [4]*Institute of Agricultural Resources and Environments, Jilin Academy of Agricultural Sciences, Changchun, P.R. China*

Abstract

Yan L., Li H., Zhang J., Zhang Z., Zhu P., Gao Q., Lu W. (2016): Response of organic nitrogen in Black Soil to long-term different fertilization and tillage practices in Northeast China. Soil & Water Res., 11: 124–130.

A long-term (18 years) effect of different fertilization and tillage management practices– fallowing treatment (no fertilizer, no cultivation); CK (no fertilizer, cultivation); N (nitrogen fertilizer); NP (nitrogen and phosphorus fertilizer); NK (nitrogen and potassium fertilizer); PK (phosphorus and potassium fertilizer); NPK (nitrogen, phosphorus, and potassium fertilizer); M1NPK (chemical fertilizer plus manure); 1.5M1NPK (1.5 times M1NPK); NPKS (mineral fertilizer plus straw); Rot (3-year crop rotation of maize-maize-soybean with M1NPK), and M2NPK (2 times manure plus mineral fertilizer) – on the content of total nitrogen and organic forms of nitrogen and the nitrogen content in different particle-size fractions were studied in topsoil (0–20 cm) in Black Soil of NE China by using the methods of Bremner. The results showed that the combined application of organic and mineral fertilizers could significantly increase the contents and proportions of total nitrogen and organic nitrogen forms in soil. Comparing to CK treatment, the content of total nitrogen and hydrolyzable nitrogen increased in the fallow and organic materials treatments. Compared with M1NPK treatment, rotation was more beneficial to increasing organic nitrogen content, especially remarkably increasing amino acid nitrogen. The nitrogen response of sand, silt, and clay was most sensitive on manure; the effects of fallow and manure treatments on sand were notable, the nitrogen content in sand with NPKS increased by 40.86% compared with CK treatment. Our results imply that fallow/rotation managements, and manure/straw application can improve soil fertility.

Keywords: cropping rotation; fallow management; hydrolyzable nitrogen; manure

Nitrogen is an important and irreplaceable element in the ecosphere and pedosphere, most of nitrogen in surface soils exists in organic nitrogen form (Chen & Xu 2008). The quantity and chemical form of organic nitrogen in soils are directly affected by the nitrogen quantity and rate of mineralization in soil (Peng *et al.* 2012). The quantity of mineralization, which has important contribution for nitrogen demand of crops and is more than 50% of nitrogen uptake of crops, is the main source of mineral nitrogen. Moreover, nitrogen distribution in particle-size fractions significantly influences the nitrogen change mechanism in soil and nitrogen sustainable management in the improvement of soil fertility (Shen *et al.* 2012).

The excessive nitrogen fertilizer application in farmland ecological system in recent years has increased

doi: 10.17221/32/2015-SWR

crop yield, however part of nitrogen lost in soil has directly entered the atmosphere by volatilization and residue nitrogen in soil has resulted in higher nitrogen content, which seriously affects drinking water and threatens the environment (Peng *et al.* 2003). Furthermore, organic nitrogen components in soils are strongly affected by poor agronomic practices (Jagadamma *et al.* 2008; Huang *et al.* 2009; Kaur & Singh 2014); whereas consistent cultivation of the same land influences soil particle size, also cultivation, manure application, and land utilization greatly influence soil particle-size fraction distribution (Wang *et al.* 2002).

Consequently, recognizing the effect of long-term different fertilization treatments and tillage managements on the content and form of organic nitrogen and nitrogen content distribution in particle-size fraction helps better understanding the relationship between crop demand and soil nitrogen supply ability (Ju *et al.* 2004). Examining the nutrition status of Black Soil is fundamental for providing suggestion on improving Black Soil fertility potential and resource sustainable development.

Therefore, the research of the content and form of organic nitrogen in soil has vital function on sustainable utilization of agronomy ecosystem, as well as nitrogen distribution in different particle-size fractions.

The aim of this study was to investigate the effect of long-term different fertilization and tillage management on organic nitrogen content and form on surface Black Soil, as well as nitrogen content changes in particle-size fraction; and then find the suitable fertilization and tillage management measures on Black Soil in NE China to improve soil fertility.

MATERIAL AND METHODS

The experimental site was established in 1990 at the Soil Fertility and Fertilizer Efficiency Long-Term Monitoring Base of the Jilin Academy of Agricultural Sciences, Jilin Province, NE China. The climate in the study area is warm-temperate, sub-humid, continental monsoon with cold winters and hot summers. The soil type in this area is Black Soil according to the Genetic Soil Classification of China, Udic Isohumisols according to the Chinese Soil Taxonomy, Udic Agriboroll according to the USDA Soil Taxonomy, or Luvic Phaeozem according to the FAO Soil Taxonomy (Gong *et al.* 1999; Liu *et al.* 2015). At present, the average depth of black topsoil is less than 30 cm due to serious soil erosion (Sun & Liu 2001). The soil organic matter, total nitrogen (TN), total phosphorus (TP), totao postassium (TK), available N, P, K, and pH in the top 20 cm soil profile were 23.3, 1.4, 1.39, 22.1 g/kg and 114, 27, 190 mg/kg,

Table1. Different fertilization application rates and cropping management during 1990–2008 in individual soil treatments (in kg/ha)

Treatments	N	P_2O_5	K_2O	Manure	Maize straw	Cultivation
Fallow	0	0	0	0	0	–
CK	0	0	0	0	0	maize
N	165	0	0	0	0	maize
NP	165	82.5	0	0	0	maize
NK	165	0	82.5	0	0	maize
PK	0	82.5	82.5	0	0	maize
NPK	165	82.5	82.5	0	0	maize
M1NPK	50	82.5	82.5	23 000	0	maize
1.5M1NPK	75	123.7	123.7	34 600	0	maize
NPKS	112	82.5	82.5	0	7 500	maize
M1NPKR	50	82.5	82.5	23 000	0	rotation
M2NPK	50	82.5	82.5	46 000	0	maize

Fallow – no fertilizer, no cultivation; CK – no fertilization, maize cultivation; rotation – maize/maize/soybean; maize – continuous maize cropping; NP – nitrogen and phosphorus fertilizer; NK – nitrogen and potassium fertilizer; PK – phosphorus and potassium fertilizer; NPK – nitrogen, phosphorus, and potassium fertilizer; M1NPK – chemical fertilizer plus manure; 1.5M1NPK – 1.5 times M1NPK; NPKS – mineral fertilizer plus straw; M1NPKR – chemical fertilizer plus manure with rotation; M2NPK – 2 times manure plus mineral fertilizer and 6.7 on average, respectively. Corn is planted at the end of April and matures in early October. Annual precipitation ranges from 450 to 600 mm, with 60–70% of the rainfall occurring in summer. No irrigation was supplied during the corn-growing season.

Experimental design. The experiment included 12 treatments, the detail fertilization application rate and tillage management are shown in Table 1. Each plot area was 400 m^2 in a completely randomized design with three replicates. Urea, calcium superphosphate, and potassium sulfate were applied as mineral fertilizer, and manure and straw as basal fertilizer. One-third of mineral nitrogen fertilizer and all mineral phosphorus and potassium fertilizers were applied at pre-sowing, and the remaining two-thirds of mineral nitrogen fertilizer were applied at a depth of 10 cm below the topsoil before jointing as top-dressing.

Sampling and laboratory procedures. Topsoil samples (0–20 cm) were taken from five locations in each replicate plot in April 2008 before corn planting, and then mixed into a composite sample. The samples were air-dried, sieved, and used to measure total N by micro Kjeldahl method; particles were classified using the method of Anderson *et al.* 1981; organic forms of nitrogen such as total hydrolyzable nitrogen (N-NH$_4$, amino sugar N, amino acid N, and unknown N) and non-hydrolyzable N (acid insoluble N) were separated using the method of soil heating with 6 mol/l HCl for 12 h described by Bremner (1965). N-NH$_4$ was recovered from hydrolyzates by steam distillation with MgO; amino sugar N was obtained by steam distillation with phosphate-borate buffer at pH 11.2 and correction for N-NH$_4$; amino acid N was determined by the ninhydrin-NH$_3$ method. The hydrolyzable N not accounted for as N-NH$_4$, amino sugar N or amino acid N, was the hydrolyzable unknown N (Li *et al.* 2014). Available nitrogen, phosphorus, and potassium were determined using NaOH hydrolyzable method, Bray I (0.03 mol/l NH$_4$F, 0.025 mol/l HCl extract) method, and atomic absorption spectrophotometric method, respectively.

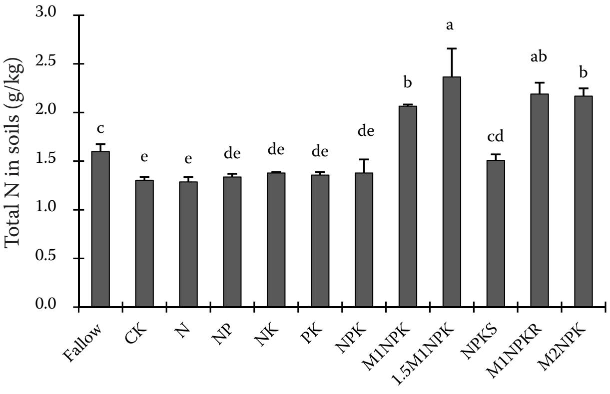

Figure 1. Total nitrogen changes of different fertilization treatments and tillage managements in Black Soil; for explanation of abbreviations see Table 1

Statistical analysis. Treatment effects were analyzed using one-way ANOVA followed by LSD test at $P < 0.05$ (SAS 8.2).

RESULTS

Changes of total nitrogen. The total N contents in Black Soil, after long-term different fertilization treatments and tillage managements, ranged from 1.29 to 2.37 g/kg (Figure 1). Compared with fallow treatment, the content of total N in the CK and mineral fertilizer treatments significantly decreased; that in NPKS treatment had no obvious change; however, manure fertilization treatments and rotation management could remarkably increase the content of total N. Compared with CK treatment, the content of total N of mineral fertilization treatments did not change and that of manure fertilization and rotation management improved significantly. Moreover, the

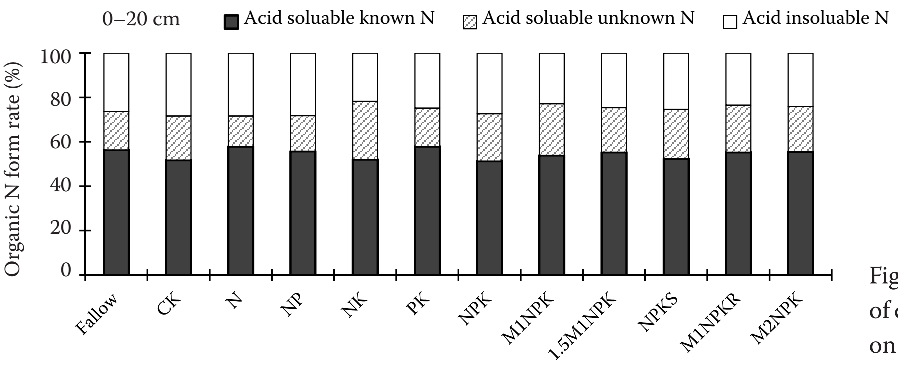

Figure 2. Organic nitrogen form rates of different treatments; for explanation of abbreviations see Table 1

doi: 10.17221/32/2015-SWR

total N content of 1.5M1NPK treatment was the peak among different treatments and that of M2NPK treatment with excessive manure brought down significantly, which indicated that the content of total N did not improve along with the increasing manure application.

Changes of organic nitrogen form. From the organic N form rate of different treatments (Figure 2), it can be seen that the acid soluble N rates in Black Soil were 71.6–78.3% of total nitrogen, which were noticeably higher than acid insoluble N. Moreover, 67–81% of acid soluble N was acid soluble known nitrogen.

For different treatments, organic manure treatments could significantly increase the acid soluble N rate (up to over 1.5 times); straw treatment and fallow treatment improved 20.5% and 25.9% of the acid soluble N rate compared with CK treatment, respectively.

Changes of acid soluble known N content. At present, the acid soluble known N mainly includes ammonium nitrogen ($N\text{-}NH_4^+$), amino sugar nitrogen (amino sugar), and amino acid nitrogen (amino acid). From the content of acid soluble known N (Table 2), it could be seen, compared with CK treatment, that the manure, fallow, and straw treatment significantly increased the content of $N\text{-}NH_4^+$, and reached on average 66.9, 25.1, and 15.6%, respectively. The content of amino acid also notably increased; and PK and 1.5M1NPK treatments could dramatically enhance the content of amino sugar, which indicated that nitrogen fertilizer would restrain the transformation from organic nitrogen to amino sugar nitrogen; suitable manure was beneficial to amino sugar nitrogen accumulation.

1.5M1NPK treatment and rotation treatment as a whole increased the content of acid soluble N; however, the opposite happened if excessive manure was applied.

Table 2. Content of three forms of acid soluble N in Black Soil (in mg/kg)

Treatment	$N\text{-}NH_4^+$	Amino sugar	Amino acid
Fallow	449^{b}	33^{b}	418^{b}
CK	359^{d}	42^{b}	273^{cd}
N	381^{cd}	36^{b}	328^{cd}
NP	389^{cd}	47^{ab}	309^{cd}
NK	413^{bcd}	53^{ab}	251^{d}
PK	383^{cd}	73^{a}	330^{c}
NPK	388^{cd}	40^{b}	277^{cd}
M1NPK	582^{a}	46^{ab}	485^{b}
1.5M1NPK	631^{a}	74^{a}	599^{a}
NPKS	415^{bc}	45^{ab}	331^{c}
M1NPKR	580^{a}	56^{ab}	573^{a}
M2NPK	604^{a}	31^{b}	568^{a}

Fallow – no fertilizer, no cultivation; CK – no fertilization, maize cultivation; rotation – maize/maize/soybean; maize – continuous maize cropping; NP – nitrogen and phosphorus fertilizer; NK – nitrogen and potassium fertilizer; PK – phosphorus and potassium fertilizer; NPK – nitrogen, phosphorus, and potassium fertilizer; M1NPK – chemical fertilizer plus manure; 1.5M1NPK – 1.5 times M1NPK; NPKS – mineral fertilizer plus straw; M1NPKR – chemical fertilizer plus manure with rotation; M2NPK – 2 times manure plus mineral fertilizer; small letters indicate significant differences ($P < 0.05$) among the different treatments

Changes of N content in different particle-size fractions. According to data of N content in different particle-size fractions (Figure 3), it can be seen that compared with CK treatment, the fallow, manure, and straw treatments significantly increased N content in different particle-size; single mineral treatments affected N content only insignificantly. The N contents of NPKS, fallow, and manure treatments were boosted by 68.75%, twice, and about 4 times in sand fraction; improved by 42.31%, 23.08%, and twice in silt fraction; as well as by 9.29%, 11.06%, and 50% in clay fraction, respectively.

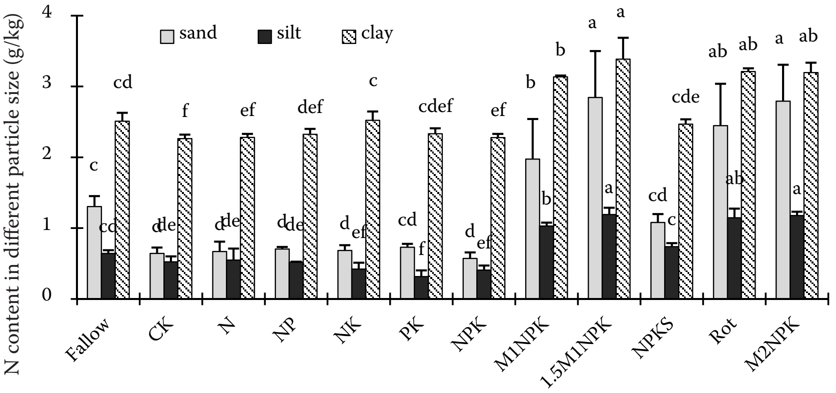

Figure 3. Nitrogen content in different particle-size fractions; for explanation of abbreviations see Table 1

doi: 10.17221/32/2015-SWR

The N content in different particle-size fractions was remarkably different in Black Soil. The range of N content in clay fraction was from 2.26 to 3.39 g/kg, which was significantly higher than that in sand and silt fractions (on average 1.9 times and 3.7 times, respectively). There was no difference of N content between sand fraction and silt fraction for single mineral treatments, whereas N content in sand fraction was higher than that in silt fraction for fallow, manure, and straw treatments.

DISCUSSION

Fallow systems are widely used in South America, Asia, and Africa as a strategy to restore soil fertility without purchasing external inputs, and are often successful in maintaining productivity in low fertile soils (Sanchez 1999; Wezel & Haigis 2002; Burgers *et al*. 2005; Couteaux *et al*. 2008; Gomez-Montano *et al*. 2013). In this work, fallow management could increase the organic nitrogen content in Black Soil, similarly as in many experiments (Hervé 1994; Masse *et al*. 2004; Miranda *et al*. 2009). However state the problem before giving reasons the "low/limited" fallow management in China could be as a country with a large population and limited arable land area, with only 0.1 ha available per capita, China is significantly less than the world average of 0.21 ha per capita in 2008 (Zhao 2012). Little opportunity to increase the area of land for cultivation, in order to guarantee food yield, resulted in fallow management vanishment (Tong *et al*. 2003; Chen 2007). Continuous high-yield without protection and recovery measures brought about soil infertility and degradation. This vicious circle phenomenon indicates that short-term fallow (once every 3–5 years) is a single and efficient measure for soil sustainable development in China.

Altering cultivation management practices, such as crop rotation, may be an effective method to suppress insect and disease pressure while maintaining yields (Buckland *et al*. 2013). Crop rotation can also increase the input of organic C and N into the soil, which enhances soil fertility (Havlin *et at*. 1990). About a half of China's maize production and a third of its soybean production come from the highly productive Black Soil in NE China (Duan *et al*. 2011; Liu *et al*. 2011). Maize-maize-soybean rotation increased organic nitrogen content in soil with the same fertilization compared with continuous cultivation of maize, which corroborates with previous findings from various rotation studies (Al-Kaisi *et al*. 2005; Ahmad *et al*. 2014). However, the area for crop rotation has shrunk in recent years in NE China due to the higher maize price and lower soybean price in the market, which has been replaced by a continuous cultivation of maize, consequently resulting in soil fertility decline.

The impact of soil degradation is difficult to reverse, the more in China, where the production still depends solely on excessive use of mineral fertilizers. Hence, early intervention in the rehabilitation of degraded soils is very important for achieving quick positive results and reversing the trend of degradation (Agbede & Ojeniyi 2009). Application of organic manures can help in forming soil aggregates and improving soil stability (Yang *et al*. 2014). The organic nitrogen content, one of important indicators to evaluate the effect of management measures on enhancing soil productivity (Mikha & Rice 2004; Manna *et al*. 2005), could be increased significantly by manure and straw application. Manure, used since ancient times in China, has played an important role in food production and improving soil fertility. Despite the long history of manure use in China, farmers have had little enthusiasm to improve soil fertility since the 1980s due to huge labour force and low economic benefits (Yang *et al*. 2014).

In some leading agricultural countries an important strategy is to apply plant residues into soil to increase soil organic carbon accumulation and hence the soil fertility (Yin *et al*. 2014). In NE China, the rates of straw rot and mineralization are restricted by low temperature and less rainfall, which affects emergence and seedling growth, thus resulting in production declines. It is therefore necessary to add a certain amount of nitrogen fertilizer and water with deep tillage to avoid the occurrence of the above phenomenon. The negative effect of higher workforce cost for manure and the restriction of straw application in the region can be improved by agricultural mechanization and agricultural technology innovation in the way of sustainable and green agriculture. However, excessive manure and straw application could not improve the organic nitrogen content in soils and it also increases the greenhouse gas emission and thus contributes to global climate change (Haefele *et al*. 2011; Knoblauch *et al*. 2011).

CONCLUSION

This study showed several trends of change of organic N after 18 years of different fertilization and tillage managements, which could contribute to the improvement of soil fertility and sustainable agriculture development of soil resource: periodic fallow management, suitable organic and inorganic mix fertilization, and rotation management can significantly increase the N content; excessive manure fertilization and single mineral fertilization management would potentially reduce soil fertility.

Successful management of soil fertility may require an integrated approach with multiple changes in cultural practices, such as crop rotation and fertilizer management.

Acknowledgements. The work was supported by the National Maize Production System in China and Special Fund for Agriculture Profession (201103003), the National Key Technology R&D Program (No. 2011BAD11B05, No. 2013BAD07B02, and No. 2013BAC09B01), the National Key Project of Water Pollution Control & Management (No. 2012ZX07201-001) and the Project of 12th five-year Plan in Education Department in Jilin Province (No. 20130062).

Reference

Agbede T.M., Ojeniyi S.O. (2009): Tillage and poultry manure effects on soil fertility and sorghum yield in southwestern Nigeria. Soil & Tillage Research, 104: 74–81.

Ahmad W., Farmanullah, Shah Z., Jamal M., Shah K.A. (2014): Recovery of organic fertility in degraded soil through fertilization and crop rotation. Journal of the Saudi Society of Agricultural Sciences, 13: 92–99.

Al-Kaisi M.M., Yin X.H., Licht M.A. (2005): Soil carbon and nitrogen changes as affected by tillage system and crop biomass in a corn-soybean rotation. Applied Soil Ecology, 30: 174–191.

Anderson D.W., Saggar S., Bettany J.R., Stewart J.W.B. (1981): Particle size fractions and their use in studies of soil organic matter I. The nature and distribution of forms of carbon, nitrogen and sulfur. Soil Science Society of American Journal, 45: 767–772.

Bao S.D. (2008): Chemistry Analysis of Soil and Agriculture. Beijing, China Agriculture Press.

Bremner J.M. (1965): Organic forms of nitrogen. In: Black C.A. (ed.): Methods of Soil Analysis. Madison, American Society of Agronomy: 1148–1178.

Buckland K., Reeve J.R., Alston D., Nischwitz C., Drost D. (2013): Effects of nitrogen fertility and crop rotation on onion growth and yield, thrips densities, Iris yellow spot virus and soil properties. Agriculture, Ecosystems and Environment, 177: 63–74.

Burgers P., Ketterings Q.M., Garrity D.P. (2005): Fallow management strategies and issues in Southeast Asia. Agriculture Ecosystems and Environment, 110: 1–13.

Chen C.R., Xu Z.H. (2008): Analysis and behavior of soluble organic nitrogen in forest soils. Journal of Soils and Sediments, 8: 363–378.

Chen J. (2007): Rapid urbanization in China: a real challenge to soil protection and food security. Catena, 69: 1–15.

Couteaux M.M., Herve D., Mita V. (2008): Carbon and nitrogen dynamics of potato residues and sheep dung in a two-year rotation cultivation in the Bolivian Altiplano. Communications in Soil Science and Plant Analysis, 39: 475–498.

Duan X.W., Xie Y., Ou T.H., Lu H.M. (2011): Effects of soil erosion on long-term soil productivity in the Black soil region of Northeastern China. Catena, 87: 268–275.

Gomez-Montano L., Jumpponen A., Gonzales M.A., Cusicanqui J., Valdivia C., Motavalli P.P., Herman M, Garrett K.A. (2013): Do bacterial and fungal communities in soils of the Bolivian Altiplano change under shorter fallow periods? Soil Biology & Biochemistry, 65: 50–59.

Gong Z.T., Chen Z.C., Shi X.Z. (1999): Chinese Soil Taxonomy. Beijing, Science Press. (in Chinese)

Haefele S.M., Konboon Y., Wongboon W., Amarante S., Maarifat A.A., Pfeiffer E.M., Knoblauch C. (2011): Effects and fate of biochar from rice residues in rice-based systems. Field Crops Research, 121: 430–440.

Havlin J.J., Kissel D.E., Maddux M.M., Claassen M.M., Long J.H. (1990): Crop rotation and tillage effects on soil organic and nitrogen. Soil Science Society of America Journal, 54: 448–452.

Hervé D. (1994): Respuestas de los componentes de la fertilidad del suelo a la duración del descanso. In: Hervé D., Genin D., Rivière G. (eds): Dinámicas del descanso de la tierra en los Andes. La Paz, IBTA, ORSTOM: 155–169.

Huang Q., Hu F., Huang S., Li H., Yuan Y., Pan G., Zhang W. (2009): Effect of long-term fertilization on organic carbon and nitrogen in a subtropical paddy soil. Pedosphere, 19: 727–734.

Jagadamma S., Lal R., Hoeft R.G., Nafziger E.D., Adee E.A. (2008): Nitrogen fertilization and cropping systems impacts on soil properties and their relationship to crop yield in the central Corn Belt, USA. Soil and Tillage Research, 98: 120–129.

Ju X.T., Liu X.J., Zhang F.S. (2004): Effects of long-term fertilization on soil organic nitrogen fraction. Scientia Agricultura Sinica, 37: 87–91. (in Chinese)

Kaur J., Singh J.P. (2014): Long-term effects of continuous cropping and different nutrient management practices on the distribution of organic nitrogen in soil under rice-wheat system. Plant, Soil and Environment, 60: 63–68.

Knoblauch C., Maarifat A.A., Pfeiffer E.M., Haefele S.M. (2011): Degradability of black carbon and its impact on trace gas fluxes and carbon turnover in paddy soils. Soil Biology and Biochemistry, 43: 1768–1778.

doi: 10.17221/32/2015-SWR

Li S.X., Wang Z.H., Miao Y.F., Li S.Q. (2014): Soil organic nitrogen and its contribution to crop production. Journal of Integrative Agriculture, 13: 2061–2080.

Liu L., Zhang K.L., Zhang Z.D., Qiu Q.Q. (2015): Identifying soil redistribution pattern by magnetic susceptibility on the black soil farmland in Northeast China. Catena, 129: 103–111.

Liu X.B., Zhang S.L., Zhang X.Y., Ding G.W., Cruse R.M. (2011): Soil erosion control practices in Northeast China: a mini-review. Soil and Tillage Research, 117: 44–48.

Manna M.C., Swarup A., Wanjari R.H., Ravankar H.N., Mishra B., Saha M.N., Singh Y.V., Sahi D.K., Sarap P.A. (2005): Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. Field Crop Research, 93: 264–280.

Masse D., Manlay R.J., Diatta M., Pontanier R., Chotte J.L. (2004): Soil properties and plant production after short-term fallows in Senegal. Soil Use and Management, 20: 92–95.

Mikha M.M, Rice C.W. (2004): Tillage and manure effects on soil and aggregate associated carbon and nitrogen. Soil Science Society of America Journal, 68: 809–816.

Miranda J., Silva L.M., Lima R., Donagemma G., Bertolino A., Fernandes N., Correa F., Polidoro J., Tato G. (2009): Fallow effects on improving soil properties and decreasing erosion: Atlantic forest, southeastern Brazil. Geophysical Research Abstracts, 11: 12276.

Peng L.F., Hao M.D., Lai L. (2003): Studies of long-term fertilization on soil organic N components. Research of Soil and Water Conservation, 10: 46–50. (in Chinese)

Peng Y.Y., Huang Y.X., Sun M. (2012): Fractions of organic nitrogen and N mineralization characteristic under long term fertilization on paddy soil. Journal of Soil and Water Conservation, 26: 173–176. (in Chinese)

Sanchez P.A. (1999): Improved fallows come of age in the tropics. Agroforestry Systems, 47: 3–12.

Shen X.R., Xu M.G., Zhang W.J. (2012): Effect of various long-term fertilizations on soil nitrogen concentration and distribution percentage in particle-size fractions. Plant Nutrition and Fertilizer Science, 18: 1127–1134. (in Chinese)

Sun J.M., Liu T.S. (2001): Desertification in the Northeastern China. Chinese Quaternary Sciences, 21: 132–153. (in Chinese)

Tong C.L., Hall C.A.S., Wang H.Q. (2003): Land use change in rice, wheat and maize production in China (1961–1998). Agriculture, Ecosystems and Environment, 95: 523–536.

Wang Y., Xu Y.C., Shen Q.R. (2002): Distribution of 15N from organic and inorganic fertilizers in different size fractions of soil and its availability. Chinese Journal of Soil Science, 33: 410–413. (in Chinese)

Wezel A., Haigis J. (2002): Fallow cultivation system and farmers' resource management in Niger, West Africa. Land Degradation & Development, 13: 221–231.

Yang Z.P., Zheng S.X., Nie J., Liao Y.L., Xie J. (2014): Effects of long-term winter planted green manure on distribution and storage of organic carbon and nitrogen in water-stable aggregates of reddish paddy soil under a double-rice cropping system. Journal of Integrative Agriculture, 13: 1772–1781.

Yin Y.F., He X.H., Gao R., Ma H.L., Yang Y.S. (2014): Effects of rice straw and its biochar addition on soil labile carbon and soil organic carbon. Journal of Integrative Agriculture, 13: 491–498.

Zhao W.W. (2012): Arable land change dynamics and their driving force the major countries of the world. Acta Ecologica Sinica, 32: 6452–6461. (in Chinese with English abstract)

Received for publication February 9, 2015
Accepted after corrections September 29, 2015

Corresponding authors:

Prof. Qiang Gao, Jilin Agricultural University, College of Resource and Environmental Science, 130118 Changchun, P.R. China; e-mail: gaoqinglunwen@163.com

Prof. Jinjing Zhang, Jilin Agricultural University, College of Resource and Environmental Science, 130118 Changchun, P.R. China; e-mail: zhangjinjing@126.com