NUTRIENT MANAGEMENT OF BUCKWHEAT BASED ON 0.01M $CaCl_2$ SOIL EXTRACTION

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Abstract

A better knowledge on 0.01M $CaCl_2$ extractable nutrient forms helps to improve the efficient use of fertilizers and organic manure. The amount of nitrate (NO_3^--N), ammonium (NH_4^+-N) and N-organic as well as phosphorus, potassium and magnesium were measured in plots of buckwheat seed production in Nyíregyháza. The nitrogen fractionation method was based on a 0.01M $CaCl_2$ extraction. The aim of this paper is to present data on the nitrogen supplying capacity of sandy and brown forest soil. The main objective was to determine the effects of nitrogen supplying capacity of soil on yield of buckwheat seed in organic agriculture.

In organic agriculture, the nutrient management is based on the self-sufficiency of the farm and the entire cycle of organic matter production and decomposition takes place within the farm boundaries and makes the farm a biological system. The rate of metabolism and the organic matter cycle are characteristic features of such production and define their activity for many years. In our experiment, nitrate nitrogen was highly correlated with the buckwheat yield and the 0.01M $CaCl_2$ extraction method can supply useful information for environmentally-friendly, sustainable agriculture. Organic nitrogen extracted by 0.01M $CaCl_2$ varied between 8-20 kg/ha in sand and 15-35 kg/ha in brown forest soil.

INTRODUCTION

Many studies (Schnurer et al. 1985, Anderson and Domsch 1989, Ross and Tate 1993) reported that soil microbial biomass and microbial activity are closely related with the organic matter content of soil. Microbial biomass correlates positively to the amount of organic matters supplied over a long period of time, but it also responds to a single application of organic matter originating from post-harvest residues or organic manure (Ocio et al. 1991). Németh et al. (1988) have shown that organic nitrogen fraction extracted by EUF is a reliable indication of mineralization during the growing season. According to Dou et al. (2000), mineralization and microbial immobilisation of nitrogen are related to soil, climatic condition and nutrient amendment. In the case of nitrogen fertilization, the rate of organic matter mineralization increases, leading to a decrease in the content of easily decomposable organic matter (Collins et al. 1992, Lovell and Jarvis (1998). Appel and Mengel (1990) reported a close relationship between N-organic content and the N mineralization potential. They also showed that nitrogen mineralization potential can be characterized with sufficient accuracy using organic N-fractions. The $CaCl_2$-extraction was found to be more appropriate than EUF or the hot water extraction method. Organic fractions extracted by 0.01M $CaCl_2$ solution were more closely related to nitrogen mineralization than the two other inorganic fractions. Similar results were reported by Houba et al. 1991, Jászberényi et al. 1994, Loch and Jászberényi 1997, Nagy et al. 2002.

According to Groot and Houba (1995), soluble organic nitrogen extracted with a 0.01M $CaCl_2$ solution is an index for the N-mineralization capacity of soils. In their experiment, the organic nitrogen fraction extracted by 0.01M $CaCl_2$ solution highly correlated with the nitrogen uptake of ryegrass (Appel and Mengel 1992). The 0.01M $CaCl_2$ extractable (NH_4^+-N + NO_3^--N) predicts plant-available nitrogen in soils with a high inorganic N fraction; thus, 0.01M $CaCl_2$ extractable (NH_4^+-N + NO_3^--N) might be widely applicable as an index for plant-available nitrogen in fertilized soils. Recent studies have showed that soluble organic nitrogen (SON) varied yearly between 8-20 kg/ha in course sand and 15-30 kg/ha in sandy loam. Minimum value was measured in winter; the maximum value in summer. Mengel et al. (2000) reported 35-45 kg/ha 0.01M $CaCl_2$ extractable organic matter. Under continuous arable cropping, Murphy et al. (2000) measured 7-18 kg/ha SON after 8 years of grass lay in the 0-25 cm soil layer, which accounted for 33-60 % of the total soluble nitrogen. Even higher SON was measured in a soil profile of 0-90 cm after ploughing up a long-term experiment on grassland. Appel and Mengel (1992) and Kulcsár et al. (1997) Lazányi et al. (2002) found a correlation between SON and nitrogen mineralization, and suggested that SON extracted by 0.01M $CaCl_2$ solution is a reliable indicator of organic N available for mineralization and plant uptake. Murphy et al. (2000) reported similar results in loamy sand with KCl-extractable N-organic.

MATERIALS AND METHODS

The objective of the soil analysis was to determine those soil conditions, which influence buckwheat seed production in organic agriculture. Soil samples were taken using a drill at depths of 0-20, 20-40, 40-60 cm at the beginning of flowering in different buckwheat field between 2004 and 2006. Samples were transported in plastic bags, and dried on wooden trays in a well-aired glasshouse. Before grinding, soil samples were cleaned of plant remains and other contamination, and stored in paper bags in a dry place until examination. Sapling places were signed and buckwheat was harvested on 2 m^2 territory. Soil pH was determined by mixing soil and water together in a 1:1 ratio. Fifty grams of air-dried soil passed through a 2-mm screen were placed into a 100-ml beaker, and 50 ml distilled water was added. The soil and water were stirred for an hour. Then, the pH of the soil solution was determined with a glass electrode and a pH meter. In Hungary, pH value is also measured in a 1 M potassium chloride solution, with an ion selective electrode. Hydrolytic acidity was measured according to the Hungarian Standard (Msz-08 0206). The prepared soil sample was shaken with normal calcium acetate, and after 16 hours, it was titrated with 0.1 n sodium hydrates in the presence of a phenolphthalein indicator. Plant nutriments were measured with atomic absorption spectrometry in a solution of 0.1 mol/l ammonium lactate + 0.4 mol/l acetous acid. Nitrate and ammonium nitrogen concentrations were measured in 0.01M $CaCl_2$ extracts for 2 h with 1:10 soil: solution ratio (Jászberényi et al. 1994) by ICP-OES. Organic nitrogen was determined by measuring the difference between total dissolved nitrogen and inorganic nitrogen (NO_3^- NH_4^+) as described by Houba et al. (1994). Principal component analysis (PCA) was used to examine the interrelationships among soil characters and buckwheat yield. Principal component analysis finds linear combinations of a set variant that maximize the variation contained within them, and displaying most of the original variability in a smaller number of dimensions. Principal components were computed from the correlation matrix of soil parameters and buckwheat yield.

RESULTS AND DISCUSSIONS

The fertility of the soil depends on the amount of easily weatherable minerals and on the direction and speed of the weathering process. When describing the sandy soils of the Nyírség, organic matter content is of primary importance. Sandy soil is poor in humus, and organic matter content is below 1%. A significant part of the Nyírség was woodland, where forest soil developed. Traces of iron accumulation can be observed near the surface. Following its deforestation, winds played important part in the formation of the surface. On the brown sandy soil of the Nyírség, rye was a traditional crop. With appropriate nutriment management, good winter wheat yields can be achieved, and even potato, cucumber and tomatoes can be grown successfully. Among legumes, white and yellow lupines are very well adapted. Most important soil parameters are listed in Table 1.

Table 1

Soil parameters of buckwheat production territory (n=90)

Parameters	0-20 cm		20-40 cm		40-60 cm		0-60 cm	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH (H_2O)*	6.2	0.5	6.1	0.5	6.0	0.5	6.1	0.5
pH (KCl)*	5.0	0.8	5.0	0.7	4.8	0.7	4.9	0.7
KA*	29.7	0.8	29.9	0.8	29.6	0.6	29.7	0.7
$CaCO_3$ (%)*	0.1	0.1	0.1		0.3		0.1	0.1
OM (%)*	0.8	0.3	0.9	0.3	0.8	0.3	0.8	0.3
y_1*	8.0	1.8	8.1	1.9	8.2	1.5	8.1	1.7
NO_3-N* (mg/kg)	3.1	1.8	4.2	2.6	4.2	3.4	3.8	2.7
P_2O_5* (mg/kg)	168.6	90.7	162.5	87.1	161.1	155.4	164.1	114.1
K_2O* (mg/kg)	251.5	72.1	256.1	72.0	214.1	60.6	240.6	70.3
Mg* (mg/kg)	53.3	28.3	54.9	28.0	58.4	26.7	55.5	27.4
Na* (mg/kg)	23.0	11.7	24.6	13.1	23.6	12.8	23.7	12.4
Zn* (mg/kg)	1.8	2.8	1.9	3.6	1.5	2.6	1.7	3.0
Cu* (mg/kg)	1.6	1.1	1.6	1.1	1.5	0.8	1.6	1.0
Mn* (mg/kg)	92.5	56.2	96.8	57.4	110.1	55.3	99.8	56.2
Silt + clay (%)*	11.6	3.1	11.8	3.4	12.0	3.7	11.8	3.4
NO_3-N** (mg/kg)	1.9	1.8	3.0	2.5	3.2	3.7	2.7	2.8
NH_4-N** (mg/kg)	2.3	0.7	2.2	0.7	1.6	0.4	2.0	0.7
Org-N** (mg/kg)	3.6	0.7	3.8	0.9	3.4	0.9	3.6	0.9
Total-N** (mg/kg)	7.8	2.4	8.9	3.4	8.2	4.5	8.3	3.5
orto-P** (mg/kg)	2.8	1.5	2.7	1.6	2.2	1.8	2.6	1.6
K ** (mg/kg)	114.1	32.9	117.8	38.3	95.7	28.9	109.2	34.6
Mg ** (mg/kg)	45.6	21.1	50.3	32.9	49.7	20.9	48.5	25.4

* = Measurement based on Hungarian standard
** = Measured in 0.01 M $CaCl_2$ extract

The primary effect of soil pH on plant growth is associated with chemical environments. The major influence of pH is on nutrient availability, especially in mineral soils. As a result of microbiological activity, nitrogen availability is highest between pH 6 and 8. The availability of phosphorus in acidic soil is reduced by precipitation and adsorption by an iron and aluminium complex. Buckwheat tolerates soil acidity more than many other crops and can grow successfully on soils with a pH between 5.5 and 6.5. It will produce reasonably well at pH between 5.0 and 6.0 if adequate P_20_5 is provided. Buckwheat has about the same acid tolerances as oat and potatoes, grows well on acid soils and gives little response to liming above a pH of 5.0, but many crops grown in rotation with buckwheat require liming. Calcium chloride ($CaCl_2$) pH is the standard used in soil taxonomy to differentiate acid and non-acid classes in mineral soils.

Nitrogen: Nitrogen is the most limiting nutrient for buckwheat production in organic agriculture of Nyírség region as a result of large need of plants and the limited ability of soils to supply nitrogen. A lack of nitrogen causes buckwheat leaves to become yellow and conversely, with an adequate supply of nitrogen, vegetative growth is rapid and foliage is dark green in colour. In vegetation period, nitrification occurs rapidly in well-drained and moist agricultural soils with a pH of 6.0 or higher and the produced nitrate is rapidly absorbed by buckwheat roots. In the experiment, there was a good correlation between total nitrogen measured in 0.01 M $CaCl_2$ extract and NO_x (nitrite and nitrate nitrogen) measured in KCl extract ($y = 1.2297x + 3.6107$) ($R^2 = 0.8692$). Soils contained more nitrogen in its upper 20 cm thick layer than in the underlying layers.

Phosphorus: Zhu et al., 2002 have demonstrated buckwheat's ability to take up phosphorus, which are released back into the soil in a plant-available form following incorporation of buckwheat residue into the soil (Bowman et al., 1998). The roots of buckwheat exude oxalic acid that allows buckwheat to grow well in soils that are high in aluminium. The mechanism for this resistance is believed to be related to the immobilization and detoxification of aluminium by phosphorus in the root tissues (Zhu et al., 2002). Additional support for phosphorus acquisition and release is provided by Annan and Amberger (1989), who hypothesized that the high activity of acid phosphates in the rhizosphere contributed to the release of phosphorus acquired under low concentrations of soil phosphorus. Buckwheat also has the capability to use phosphorus from organic sources. Buckwheat shows little response to phosphate content of soil, because buckwheat uses mostly insoluble phosphorous sources. The phosphorus values reported in a soil test result may not accurately reflect the amount of phosphorus available to the buckwheat crop, but two methods sow good correlation ($y = 0.0143x + 0.3026$) ($R^2 = 0.7245$). It neither is nor expected that buckwheat will respond to additional phosphorus at soil tests above 180 mg P_2O_5 /kg soil.

Potassium: The potassium is released and eventually removed from the soil by leaching. Sandy soils also have low capacity to supply potassium for plant growth. Many researchers have found, that biotite is a good source of potassium. The relative weathering rates and release of potassium from microcline, muscovite, and biotite have been reported to be 1.0, 1.8, and 190, respectively. There is also evidence that roots play a role in the removal of potassium from biotite, but plants differ in their capacity to use biotite potassium. The rapid weathering rate of biotite accounts for its low content in most soils, whereas the very slow weathering rate of muscovite accounts for its presence in the clay fraction of most soils. The weathering of feldspar in the sand fraction also contributes to the release of potassium in some sandy soil. Studies also have shown that the amount of exchangeable potassium in many soils is about equal to the annual uptake of buckwheat, and that the amount in solution at any given instant is equal to 1 % to 3 % of the exchangeable potassium. Assuming that the solution potassium is equal to 2 % of the exchangeable potassium, the soil solution in effect will have to be depleted and replaced with potassium about 50 times during the growing season. The potassium values reported in a soil test result may not accurately reflect the amount of potassium available to the buckwheat crop, but two methods sow good correlation ($y = 0.4328x + 5.0668$), ($R^2 = 0.7733$). Diffusion of potassium ion through soil water to roots is the most limiting step in potassium uptake during the growing season. The results are highly dependent on soil physical characteristics, the forms and amounts of subsoil nutrients. It neither is nor expected that buckwheat will respond to additional potassium at soil tests above 250 mg K_2O/kg soil.

Magnesium: Magnesium is an important nutrient for plants in Nyírség region. In the organically managed buckwheat seed production territory, the amount of 0.01 M extracted magnesium varied between 20 and 100 mg/kg soil. The magnesium content of the acid soils of the Nyírség is usually low, but magnesium plays an important role in forming the characteristics of silicate minerals. The ion size of magnesium is similar to that of aluminium, so it can often substitute for it. In soil, there is a balance of three different forms of magnesium: water dissolvable, replaceable and one with fixed by silicates. AL extracted magnesium found in the cultivated layers of soil is 100-300 kg/ha, which equals 2-5% of the total magnesium content. Buckwheat uses 3 kg of magnesium oxide to produce 1 t of main crop and the by-product and the amount of magnesium extracted by plants is 30-50 kg/ha, which represent a negative magnesium balance. There was a positive correlation between magnesium extracted by 0.01 M $CaCl_2$ procedure and conventional AL method ($y = 0.7284x + 6.9824$), ($R^2 = 0.934$).

Principal component analysis

In Hungary, fertilizer recommendations are based on crop requirements, soil parameters, and the drought index, the supply of nitrogen by crop residues, as well as the nitrogen and organic matter contents of the soil. This comprehensive study of buckwheat production allows the use of statistical methods to point out relationships between soil characteristics and buckwheat yield. Factor analysis can serve as an ideal tool in describing the state of the soil with the introduction of complex variables. We carried out the examinations using the SPSS program package.

Table 2

Principal component analysis

Components	C-1	C-2	C-3	C-4
Variance (%)	47,52	27,20	7,97	6,39
Buckwheat yield (t/ha)	-0,03	**0,98**	-0,14	0,05
pH (KCl)	**-0,72**	0,02	**0,42**	**0,47**
pH (H2O)	-0,38	0,37	**0,57**	**0,51**
KA	**0,94**	0,09	0,13	0,10
OM (%)	**0,84**	-0,12	-0,04	0,18
NO3+NO2 (mg/kg)	-0,01	**0,94**	0,18	-0,05
P2O5 (mg/kg)	**0,98**	0,00	0,00	-0,05
Mg (mg/kg)	**0,94**	-0,01	0,13	-0,09
K2O (mg/kg)	**0,93**	-0,07	-0,11	0,31
Na (mg/kg)	**0,68**	-0,04	**0,48**	-0,35
Zn (mg/kg)	**0,95**	0,10	0,00	0,17
Cu (mg/kg)	**0,99**	0,08	-0,05	0,05
Mn (mg/kg)	**0,98**	0,05	0,02	0,14
Clay + silt (%)	**0,90**	0,25	0,11	-0,09
Mg (mg/kg)	**0,74**	0,44	0,31	-0,05
K (mg/kg)	**0,55**	-0,50	-0,36	0,16
NO3-N (mg/kg)	0,02	**0,94**	-0,18	0,10
NH4-N (mg/kg)	0,18	**-0,92**	-0,26	0,14
N-org (mg/kg)	-0,06	**0,61**	**-0,66**	0,21
Total-N (mg/kg)	0,03	**0,92**	-0,25	0,13
Orto-P (mg/kg)	-0,07	0,47	-0,06	**-0,63**

In the second factor, buckwheat yield sows positive relationship with NO_x and NO_3-N, N-org and total –N measured in 0.01 M $CaCl_2$ extracts (Table 2). In the sandy soils of Nyírség region, buckwheat respond well to nutrients and removes approximately 22 kg of N, 15 kg of P_20_5, and 36 kg of K_2O from the soil to produce 1 t/ha yields. Too much nitrogen increase weed pressure, encourages excessive vegetative growth, causes lodging, decreases grain yield. Excess nitrogen responses are especially noticeable when phosphorus is deficient. In spring time, when buckwheat is growing fast, nitrogen mineralization is rapid in organic agriculture and additional nitrogen is unnecessary.

DISCUSSION

The 0.01 M $CaCl_2$ extraction method has proved reliable for determining the nitrogen supplying capacity of soils in organically managed buckwheat field, where organic matter content varied between 0.3% and 1.6 %, while 0.01 M $CaCl_2$ soluble organic nitrogen content varied between 2-6 mg/kg soil. The nitrogen cycle of soils is a part of the earth's overall nitrogen cycle and eventually nitrogen returns to the atmosphere through a series of processes such as fixation, mineralization, nitrification, immobilisation and denitrification. A significant part of the soil nitrogen occurs in organic matter and it derives from the biological fixation of the nitrogen of the atmosphere. The nitrogen content of the sandy soil is between 0.02 and 0.12 %, corresponding to a total amount of 0.5-2.5 t/ha in the upper, cultivated layer. The amount of nitrogen available for plants is much less, but influenced by soil organic matter content. A large part of the nitrogen derives from organic matter of floral, faunal and microbiological origin. The amount of nitrogen mineralised tends to be related to the amount of soil organic matter and environmental conditions. Brown forest soils in Nyírség region are low in organic matter and the nitrogen supplying capacity was 15.6 kg/ha/year in the fallow treatment of Westsik crop rotation experiment (Lazányi, 2003), where roots and green manure increased the nitrogen supplying capacity of soil by more than 100 %. Buckwheat yield sows positive relationship with NO_3-N, N-org and total –N measured in 0.01 M $CaCl_2$ extracts.

REFERENCES

1. Anderson T., Domsch K.H. (1989): Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil. Biol. Biochem., 21: 471–479 p.
2. Annan, A. and L. Amberger 1989. Phosphorus efficiency of buckwheat. Zeitschift fur Pflanzenern hrung und Bodenkunde 152: 181-189 p.
3. Appel, T., Mengel K. (1990): Importance of organic nitrogen fractions in sandy soils, obtained by electro-ultrafiltration or $CaCl_2$ extraction, for nitrogen mineralization and nitrogen uptake of rape. Biology and Fertility of Soils. 10. 97-101 p.
4. Appel, T., Mengel K. (1992): Nitrogen uptake of cereals grown on sandy soils as related to nitrogen fertilizers application and soil nitrogen fractions obtained by electro-ultrafiltration (EUF) and $CaCl_2$ extraction. European Journal of Agronomy. 1. 1-9 p.
5. Bowman, G., C. Shirley and C. Cramer. 1998. Managing cover crops profitably. Sustainable Agriculture Network Handbook Series, Book 3. Available online at: http://www.sare.org/
6. Collins H.P., Rasmussen P.E., Douglas C.L., (1992): Crop rotation and residue management effect on soil carbon and microbial dynamics. Soil Sci. Soc. Am. J., 56: 783–788.
7. Dou, H., Alva, A.K., Appel, T. (2000): An evaluation of plant-available soil nitrogen in selected sandy soils by Electro-Ultrafiltration, KCl, and $CaCl_2$ extraction methods. Biol Fertil Soils, 30:328-332 p.
8. Groot, J. J. R., Houba, V. J. G. (1995): A comparison of different indices for nitrogen mineralisation. Biology and Fertility of Soils. 19. 1-9 p.
9. Houba V.J.G., Jászberényi I., Loch J. (1991): Application of 0.01 M $CaCl_2$ as a single extraction solution for evaluation of the nutritional status of Hungarian soils. Debreceni Agrártudományi Egyetem Tudományos Közleményei, Tom. 30. 85-89 p.
10. Houba V.J.G., Novozamsky I., Huybregts A.W.M., van der Lee J.J. (1986): Comparison of soil extractions by 0.01M $CaCl_2$, by EUF and by some conventional extraction procedures. Plant Soil, 96: 433–437 p.
11. Jászberényi I., Loch J., Sarkadi J. (1994): Experiences with 0.01 M calcium chloride as an extraction reagent for use as a soil testing procedure in Hungary. International Symposium on Soil Testing and Plant Analysis, August 14-19, Olympia, USA. Megjelent: Commun. Soil Sci. and Plant Anal. **25**. 1771-1777 p.
12. Kulcsár L. - Debreczeni K. - Jászberényi I. - Loch J. (1997): Investigation of the soil N-fractions in special consideration of the N-fertilizer recommendation for sugarbeet. Poster on the 11th World Fertilizer Congress 7-13. September 1997. Gent, Belgium.
13. Lazányi J. (2003): Results of sustainable production in Westsik's crop rotation experiment. Westsik Vilmos Foundation for Rural Development. Nyíregyháza. 1-205 p. ISBN: 963 472 724 7
14. Lazányi J., Loch J., Jászberényi I. (2002) Analysis of 0.01 M $CaCl_2$ soluble organic nitrogen in the treatments of Westsik's crop rotation experiment. Agrokémia és Talajtan. 51. 1-2. 79-89 p.
15. Loch J., Jászberényi I. (1997): The 0.01 M $CaCl_2$ solution as a multi-element soil extractant - application and experiences in Hungary. In: Gy. Filep (ed.) „Land use and Soil Management" Rexpo Ltd 1997. Debrecen, Hungary 175-184 p.
16. Lovell R.D., Jarvis S.C. (1998): Soil microbial biomass and activity in soil from different grassland management treatments stored under controlled conditions. Soil Biol. Biochem., 30: 2077–2085 p.
17. Mengel, K., Schneider B., Kosegarten H. (2000): Nitrogen compounds extracted by electroultrafiltration (EUF) or $CaCl_2$ solution and their relationships to nitrogen mineralization in soils. Journal of Plant Nutrition and Soil Science. Vol. 162. 139-148.
18. Murphy, D. V., MacDonald, A. J., Stockdale, E. A. (2000): Soluble organic nitrogen in agricultural soils. Biol Fertil Soils. 30. 374-387 p.
19. Nagy P.T., Jászberényi I., Loch J. (2002): A trágyázás hatása a 0.01 M kalcium-kloridban oldható nitrogénformák mennyiségére a nyírlugosi tartamkísérletben. In.: Láng et al.: Tartamkísérletek, Tájtermesztés, Vidékfejlesztés Nemzetközi Konferencia I., 143-148. p.
20. Németh, K., Bartels, H., Vogel, M., Mengel, K. (1988): Organic nitrogen compounds extracted from arable and forest soils by electro-ultrafiltration and recovery rates of amino acids. Biol Fertil Soils 5: 537-539 p.
21. Ocio J.A., Martinez J., Brookes P.C. (1991): Contribution of straw-derived N to total microbial biomass N following incorporation of cereal straw to soil. Soil Biol. Biochem., 23: 655–659 p.
22. Ross D.J., Tate K.R. (1993): Microbial C and N, and respiratory activity in litter and soil of southern Beech (Nothofagus) forest: distribution and properties. Soil Biol. Biochem., 25: 477–483 p.
23. Schnurer J., Clarholm M., Rosswall T. (1985): Microbial biomass and activity in agricultural soil with different organic matter contents. Soil Biol. Biochem. 17: 611–618 p.
24. Zhu, Y. G., Y. Q. He, S. E. Smith, and F. A. Smith. 2002. Buckwheat (Fagopyrum esculentum Moench) has high capacity to take up phosphorus (P) from calcium (Ca)-bound source. Plant Soil 239:1-8 p.