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Amounts of nitrogen and carbon returned to soil depending on green manure and the effect on winter wheat yield

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Abstract. The trials were carried out during the 2006–08 growing seasons at the Department of Field Crop Husbandry in the Estonian University of Life Sciences. A field experiment was conducted to investigate the effect of green manure treatments on the yield and yield quality of winter wheat. The total phytomass of leguminous green manures ploughed into soil in 2007 varied from 10.3 Mg ha^{-1} with the bird's foot trefoil to 13.9 Mg ha^{-1} with the white sweet clover. The root mass of legumes comprised 37–54% of the total biomass. The amount of carbon applied into the soil with the green material and roots of legumes varied from 4.43 Mg ha^{-1} to 5.98 Mg ha^{-1}. The amounts of nitrogen were up to 274 kg of N ha^{-1}. The highest wheat yields were attained in treatments with lucerne and red clover as preceding crops. Compared to the N_0 treatment, the extra yield reached 3.26 Mg ha^{-1} with green manures. Both green manures and mineral fertilizers enhanced the quality of the winter wheat yield, but the results did not vary among different green manures.

Key words: green manure, nitrogen, carbon, grain yield, protein, gluten index, volume weight

INTRODUCTION

One of the key factors in increasing the yield and quality of crops is appropriate manuring. In the present economical situation the sales prices of crops have decreased considerably compared to previous years, whereas the prices of pesticides and fertilizers have risen, leaving the farmers with fewer financial resources. Given the increased prices of mineral fertilizers, leguminous green manure crops have become important organic fertilizers both in organic as well as traditional production due to their ability to bind air nitrogen and carry nutrients (P, K) to deeper plough layers. Biological N fixation is one of the primary sources of N in organic farming (Berry et al., 2002). Some mineral fertilizers used in agriculture can be replaced by green manuring, which reduces the cost of production (Poutala et al., 1994). A high soil N fertility, e.g. from incorporated green manure crops, imply a risk of N leaching (Askegaard et al., 2005). Organic matter content is generally regarded as one of the main indicators of soil quality (Schjønning et al., 2004). Organic matter helps to improve the humus status of soil, thus also improving the soil structure, and physical as well as hydrophysical properties. Abundant application of organic matter into soil has a positive effect on soil biota and the soil's biological activity. Also, the nutrients released from organic matter increase the yield of succeeding crops. Beneficial effects of the preceding crop on water use efficiency and reduction in crop diseases can in some cases account for up to 50% of the yield response of the succeeding crop (Harper et al., 1995).

Green manure crops are most effective in organic farming where the main issues concern the application of nutrients into the soil and growing grains with high-quality properties. One of the major benefits of increasing the soil organic N levels through green-manure crops is an increase in the mid-growing season N mineralisation, which in most cases translates into a higher grain N content (Olesen et al., 2009). In the production of high-quality milling wheat, late manuring with nitrogen is especially important. Under good humidity conditions, the optimum period for late manuring is the heading phase. Manuring stimulates growth in protein content during this period. Nitrogen applied at a later period primarily enhances gluten content in wheat (Järvan et al., 2007). Applying the total amount of nitrogen fertilizer at the beginning of the growing period could result in superfluous vegetative growth, lodging and decrease in the yield and quality of wheat (Brown et al., 2007). With green manure, large amounts of nitrogen are applied into the soil, but nitrogen is released gradually because organic matter is decomposed over a long period of time. With green manure, crops are provided with nitrogen throughout their growing period. Research has shown that 82–84% of the red clover's effect is realized in the first year, and 16–18% in the second year as an after-effect (Viil & Võsa, 2005).

MATERIALS AND METHODS

The trials were carried out during the 2006–08 growing seasons in the Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences (58°23′N, 26°44′E). The size of each test plot was 30 m^2, with 4 replications. The soil was sandy loam Stagnic Luvisol in the WRB 1998 classification. The mean characteristics of the humus horizon were as follows: C_{org} 1.3–1.4 %, N_{tot} 0.10–0.11%, P 3.3–3.5 mg $100g^{-1}$, K 15-17 mg $100g^{-1}$.

Plant analyses were conducted at both the Department of Soil Science and Agro-Chemistry of EMU and the Estonian Agricultural Research Centre laboratories. Acid digestion by sulphuric acid solution was used to determine N, P, and K content in plant material. The Dumas Combustion method was used to determine the content of carbon in the plant biomass. The crude protein (CP) concentration in feed was determined using the Kjeldahl procedure. Wet gluten content (WGC) and gluten index (GI) were determined by ISO 21415-2:2006. Yield (Y), 1000 kernel weight (TKW) and volume weight (VW) was calculated as the average of 8 replications (2 from each plot).

The preceding crop in 2005 was spring barley. The field experiment was established in 2006 using the following variants of green manure crops and fertilisation:

Variant A) spring barley (*Hordeum distichon* L.) with undersowings of (i) red clover (*Trifolium pratense),* (ii) lucerne *(Medicago sativa),* (iii) hybrid lucerne *(Medicago media),* (iv) bird's-foot trefoil *(Lotus corniculatus),* (v) white sweet clover *(Melilotus albus)*

Variant B) spring barley with mineral fertiliser rates (i) N_0 – the control variant (ii) N_{100}, (with cereal sowing); the same, for 2007.

The succeeding crop winter wheat (*Triticum aestivum*) "Ramiro"was sown at the beginning of September 2007. The seed rate of germinating grains of cereals was 500 m^{-1} every year. Green manure crops were sown according to the following norms: red clover 7.5 kg ha^{-1}, lucerne 6.5 kg ha^{-1}, hybrid lucerne 10 kg ha^{-1}, bird's-foot trefoil 6 kg $ha^{-1}$and white sweet clover 18 kg ha^{-1}. In 2006 barley straw was removed. In the beginning of August 2007 the biomass of legumes and barley straw were ploughed into the soil. Samples of the aboveground biomass (0.25 m^{-2} from each plot) were taken before harvesting the cereals. The root mass was taken from 0–30 cm in depth (by 10*20 cm frame from each plot), washed, dried and weighed. Biomass from the undersowing samples was separated into leguminous and cereals.

In variants with undersowings (A) the aboveground biomass and the root mass of leguminous crops were measured before ploughing.

The vegetation period of 2006 had a high temperature regime and low precipitation. The first half of the vegetation period (up to 31 July) was very dry, with only half of the average precipitation in Estonia. In 2007, the average temperature was higher whereas the average precipitation was lower than in previous years. The drought reached its peak in August. The average temperature of the 2008 vegetation period was lower than in many previous years. Drought in spring and high average precipitation in August had an influence on the yield and quality of wheat.

The analysis of variance (ANOVA) was used to evaluate the impact of the experimental variants on the yield and yield quality.

The relationship between the C/N ratio (y) and the nitrogen content (x, %) of the organic matter is reflected in the following regression equation:

$$y\ (C/N) = 42.977x^{-1.0035},\ R^2 = 0.99;\ p < 0.000.$$

The objectives of the trial include examining the capacity of the second vegetation year leguminous green manures to form biomass; analyzing the amount of nitrogen and carbon returned to soil, and determining the effect of these factors on the yield and quality of the succeeding crop.

RESULTS AND DISCUSSION

In 2007 barley pure sowings, the amounts of nitrogen returned to the soil with straw and roots were 39 kg ha^{-1} and 57 kg ha^{-1} on the background of N_0 and N_{100} respectively. The respective amounts for carbon were 1.83 and 2.62 Mg of C ha^{-1}. The phytomass returned to the soil in barley sowings was 4.26 and 6.10 Mg of dry matter ha^{-1} on the background of N_0 and N_{100} respectively.

The total phytomass of leguminous green manures ploughed into soil in 2007 varied from 10.3 Mg ha^{-1} with the bird's foot trefoil to 13.9 Mg ha^{-1} with the white sweet clover. The phytomass of hybrid lucerne was 12.5 Mg ha^{-1}. The formation of legume mass is influenced by various factors. The trials have shown that red clover is more stable and resistant to unfavourable conditions than other legumes (Talgre, et al., 2009a, 2009b). White sweet clover and lucerne are more sensitive to climatic and agrotechnical factors.

The root mass of legumes comprised 37–54% of the total biomass. The amount of carbon applied to the soil with the green material and roots of legumes varied from 4.43 Mg ha^{-1} (bird's foot trefoil) to 5.98 Mg ha^{-1} (white sweet clover). The amount of nitrogen returned to the soil was dependent on the leguminous crop; up to 274 kg of N ha^{-1} were applied into the soil (Fig. 1) based on the treatment. Earlier research has also proved that leguminous crops can bind 200–300 kg of N ha^{-1} per year (Viil & Võsa, 2005; Talgre, et al., 2009b). The biological production of green manures, as well as the amounts of nitrogen they bind and the C/N ratio of organic matter vary according to the crop species, soil and farming techniques. The decomposition of organic matter in soil is largely determined by its C/N ratio. The smaller the C/N ratio of organic matter and the greater its nitrogen content, the more nitrogen is released into soil from green manure mineralisation (Kumar & Goh, 2002). The C/N ratio of the applied organic matter varied significantly. The C/N ratio of barley straw and the aboveground biomass of leguminous crops were 65–69 and 20–23 respectively.

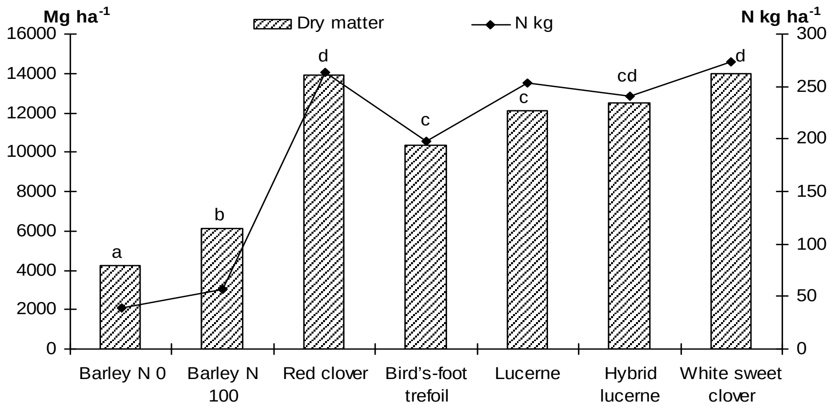

Figure 1. Quantities of dry matter (Mg ha^{-1}) and N (kg ha^{-1}) applied into soil in 2007. Means followed by the same letter are not significantly different ($P < 0.05$).

In the 2007 trial, winter wheat was sown as a succeeding crop. Despite the drought in spring, the conditions were favourable for the yield formation of winter crops, though the quality of the yield was influenced by the rainy harvesting period. Aside from weather, other factors that may influence the yield of winter wheat are crop variety and nutrient supplies. Traditionally, winter wheat is known by its higher yield potential and spring wheat by better baking quality (Swenson, 2006).

The highest wheat yields were attained in treatments with lucerne and red clover as preceding crops. Compared to the N_0 treatment, the extra yield reached 3.26 Mg ha^{-1} with green manures. After the use of bird's foot trefoil, the yield was equal to the treatment in which 100 kg of mineral nitrogen had been applied (Fig. 1). Also Maiksteniene and Arlauskiene (2004) show that the highest wheat yield is attained when wheat is grown after lucerne as a preceding crop, the yield being 18.5% higher than after clover. Higher grain yields are usually associated with lower protein concentration (Blackman & Payne, 1987). Protein is a primary quality component of cereal grains. Protein content can be increased with higher nitrogen fertilizer norms (Peterson, 1976). In the present trial, protein content increased compared to the N_0 treatment, but remained lower than the protein content of wheat (13–15%). The protein content of wheat grains was 11.7–12.8% on the background of green manures, and had a lower level in the treatment where hybrid lucerne and bird's foot trefoil had been grown as preceding crops. Protein content is positively correlated with wet gluten content (Fredericson et al., 1998) which is strongly influenced by the growing environment (Grausgruber et al., 2000). The trial also showed that the wet gluten index increased according to a rise in protein content. One of the most used criteria of wheat quality is volume weight, which is an indication of the density and soundness of the wheat. Volume weight is influenced by many factors, including fungal infection, insect damage, kernel shape and density, agronomic practice and the climatic and weather conditions (Gaines et al., 1997). In the trial, the volume weight remained low. After the application of green manures, the volume weight of all treatments was higher than the volume weight of the N_0 treatment (Table 1).

Table 1. Yield and yield quality of winter wheat *Ramiro* depending on preceding crop.

Preceding crop	Y (Mg ha^{-1})	TKW (g)	VW (gl^{-1})	CP (%)	WGC (%)	GI (%)
Barley N0	2.89	29.8	753	9.4	x	x
Barley N_{100}	5.78	40.0	796	12.9	30.8	55
Red clover	5.95	40.3	801	12.2	23.3	88
Lucerne	6.15	40.8	802	11.9	23.0	87
H. lucerne	5.98	40.6	800	1.7	22.8	92
Sweet clover	5.39	39.8	800	12.2	24.6	98
Bird's foot trefoil	5.78	40.4	799	11.8	22.5	91
LSD $_{0.05}$	582	1.4	5.3			

x – non-washable

Kernel weight, usually expressed in grams per 1000 kernels, is a function of kernel size and density. Kernel weight increased in all treatments compared to the N_0 treatment, but there was no plausible difference between green manure treatments.

Wet gluten, obtained my mixing flour and water, increases the volume of bread. Grains should contain at least 26% of wet gluten, with the best wet gluten content being 28–29%. Wet gluten content in grains was increased both with mineral fertilizers as well as on the background of the after-effect of green manures, but remained below the norm in all treatments. Kangor et al. (2007) have also shown that wet gluten content increases both with root as well as foliar fertilization.

Gluten index is used to measure the quality of wet gluten: the optimum index is 60–90 and the satisfactory index, 41–59. In treatments where green manures were grown as preceding crops the gluten index rose by 33–43 units as compared to the N_{100} treatment. The increased gluten index is an indication of the higher quality of wet gluten and enhanced baking properties.

CONCLUSION

The biological production of green manures, as well as the amounts of nitrogen they bind and the C/N ratio of organic matter, vary according to the crop species. The highest phytomass and amount of nitrogen returned to soil was obtained by growing white sweet clover and red clover; the lowest respective results were obtained with bird's foot trefoil. The winter wheat yield was lower after white sweet clover than after other leguminous preceding crops despite the highest amount of nitrogen applied into the soil. This is probably due to the slower decomposition of white sweet clover. The highest wheat yields were attained in treatments with lucerne and red clover as preceding crops. Both green manures and mineral fertilizers enhanced the quality of winter wheat yield, but the results did not vary among different green manures.

REFERENCES

Askegaard, M., Olesen, J.E., Kristensen, K. 2005. Nitrate leaching from organic arable crop rotations: effects of location, manure and catch crop. *Soil Use Manage*. **21**, 181–188.

Berry, P.M., Sylvester-Bradley, R., Philipps, L., Hatch, D.J., Cuttle, S.P., Rayns, F.W., Goslin, P. (2002). Is the productivity of organic farms restricted by the supply available nitrogen? *Soil Use Manage*. 1**8**, 248–255.

Blackman, J.A.and Payne, P.I. 1987 Grain quality. In: Lupton, F.G.H. (ed) *Wheat Breeding. Its scientific basis*. Great Britain, pp 455–485.

Brown,B., Westcott, M., Christensen, N., Pan, B., Stark, J. 2007. Nitrogen Management for hard Wheat Protein Enhancement. http://info.ag.uidaho.edu/PDF/PNW/PNW0578.pdf (20. 02. 2007).

Frederiksson, H., Salomonsson, L., Andersson, L., Salomonsson, A-C. 1998. Effects of protein and starch characteristics on the baking properties of wheat cultivated by different strategies with organic fertilizers and urea. *Acta Agric. Scand.*, *Sect. B*, **8**, 49–57.

Gaines C.S., Finney P.L., Andrews C. 1997. Influence of kernel size and shriveling on soft wheat milling and baking quality. *Cereal Chem*., **74**(6), 700–704.

Grausgruber, H., Oberforster, M., Werteker, M., Ruckenbauer, J., Vollmann, J. 2000. Stability of quality traits in Austrian-grown winter wheats. *Field Crop Research*. **66,** 257–267.

Harper, L.A., Hendrix, P.F., Langdale. G.W. and Coleman, D.C., (1995). Clover management to provide optimum nitrogen and soil water conservation. *Crop Science.*, **35**: 176–182.

Järvan, M., Adamson, A., Edesi, L. 2007. Talinisu väetamisest lämmastiku ja väävliga. *Soovitusi põllukultuuride kasvatajale.* Saku, lk. 9–13. (in Estonian)

Kangor, T., Tamm, I., Tamm, Ü., Ingver, A. 2007. Väetamise mõju ja tasuvus suviteraviljadel. *Millest sõltub teravilja saagikus*. Jõgeva SAI, lk. 4–13. (in Estonian)

Kumar, K., Goh, K.M. 2002. Management practices of antecedent leguminous and non–leguminous crop residues in relation to winter wheat yields, nitrogen uptake, soil nitrogen mineralization and simple nitrogen balance. *European Journal of Agronomy*. **16**: 295–308.

Maiksteniene S. and Arlauskiene A. 2004. Effect of preceding crops and green manure on the fertility of clay loam soil. *Agronomy Research.* **2** (1), 87–97.

Olesen J. E., Askegaard M., Rasmussen I. A. 2009. Winter cereal yields as affected by animal manure and green manure in organic arable farming. *European Journal of Agronomy*. **30,** 119–128.

Peterson, D. M., 1976. Protein concentration, concentration of protein fractions and amino acid balance in oats. – *Crop Science*, **16**, 663–666.

Poutala, R.T, Kuoppamäki, O., Korva, J. &Varis, E. 1994. The performance of ecological, integrated and conventional nutrient management systems in cereal cropping in Finland. *Field Crops Research.* **37**, 3–10.

Schjønning, P., Elmholt, S., Christensen, B.T., 2004. Soil quality management – synthesis. In: Schjønning, P., Elmholt, S., Christensen, B.T.(Eds.), *Managing Soil Quality: Challenges in Modern Agriculture*. CAB International, p. 368.

Swenson, A. 2006. Wheat Economics: Spring versus Winter. www.ext.nodak.edu/extnews/newsrelease/2006/083106/12wheate.htm - (05.11.2009)

Talgre, L., Lauringson, E., Roostalu, H., Astover, A., Eremeev, V., Selge, A. 2009a. The effects of pure and undersowing green manures on yields of succeeding spring cereals. *Acta Agric. Scand. Sect. B – Soil and Plant Sci.*, 2009; **59**, (1), 70–76.

Talgre, L., Lauringson, E., Roostalu, H,. Astover, A., Makke, A. 2009b. Phytomass formation and carbon amount returned to soil depending on green manure crop. *Agronomy Research*. **7**, (Special Issue 1), 517–521.

Viil, P., Võsa, T. 2005. Liblikõielised haljasväetised. EMVI Infoleht 148, 16 pp. (in Estonian)

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Control possibilities of *Apera spica-venti* (L.) P.Beauv. in winter wheat with autumn and spring applications of herbicides in Latvia

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Abstract. This paper presents results on weed control and yield responses in winter wheat grown after winter oilseed rape and after winter wheat, using data from field trials with a range of herbicides registered for use in Latvia that were applied either in the autumn or in the spring. *Apera spica-venti* was the dominant weed in these trials, accounting for 70–80% of the total weed biomass. Spring application of herbicides did not provide good control of *Apera spica-venti* up to harvest time: the infestation at application time was more than 140 plants per m^2. Autumn application of appropriate herbicides gave satisfactory control of *Apera spica-venti* up to harvest time in the following year. All herbicide treatments significantly increased crop yield but the autumn applications gave significantly greater increases than nearly all spring applications.

Key words: *Apera spica-venti*, winter wheat, yield, herbicide application in autumn and in spring

INTRODUCTION

Economic pressures have led many arable farmers in Latvia and other countries of northern Europe to adopt crop rotations based on the sequence of winter oilseed rape followed by winter wheat or successive crops of winter wheat. From 2000–2008 the areas of winter wheat and oilseed rape in Latvia increased annually: winter wheat, from 117.4 to 170.4 thousand ha; oilseed rape from 6.9 to 82.6 thousand ha. On the larger farms the main crop rotation is now based on winter wheat and winter oilseed rape.

These rotations have brought about changes in the weed flora such that *Apera spica-venti* is now an important target for control and serious yield losses have occurred in winter wheat crops where the *Apera spica-venti* has not been controlled effectively. For example, Bartels (2004) found a grain yield loss of 3 t ha^{-1} in untreated plots which were infested with 200 *Apera spica-venti* plants m^{-2} compared to treatments providing successful grass weed control. Increased infestations in winter cereals have also been reported by Danish researchers: Andreasen & Stryhn (2008) and Melander et al. (2008). In a ranking of the 15 most important weed species found in winter cereal crop systems in 26 European countries, *Apera spica-venti* was ranked fifth among all weeds and first among grasses (Schroeder et al., 1993). Weed population in treatments without herbicide application reveal the efficiency of weed management in previous years. Weed populations were more influenced by the preceding crop and by the timing of herbicide application than by the tillage system

(Streit et al., 2003). To improve the efficiency of weed control and to reduce reliance on herbicides in cropping systems with reduced tillage intensity, Streit and his co-workers stated that further research was needed to determine the beneficial effects and the optimization of crop rotation and appropriate weed control.

In recent years the average air temperatures in Latvia, during both the autumn and the spring-summer growing periods, have generally been higher than the long-term averages. These warmer temperatures have provided improved conditions for the germination and development of weeds in autumn-sown crops.

Cereals are most sensitive to competition from weeds in their early stages of growth and, especially in autumn sown crops, grass weeds can be extremely competitive in the early stages, particularly in cereals established with reduced cultivations (Tottman et al., 1982). Autumn application of herbicides will control weeds that could survive during winter to affect winter wheat growth and will provide better conditions for competition by the crop when vegetative growth begins in spring (Pilipavičius et al., 2010). Competition from autumn germinated broad-leaved weeds is generally less severe than that from grass weeds (Tottman et al., 1982). The most favourable application timing for grass weed control is between the 3-leaf stage and the beginning of stem elongation (Hacker et al., 1999). The importance of herbicides that can control grass weeds and dicotyledonous weeds by autumn application is described by Brink & Zöllkau (2004).

To control the yield-reducing weeds, wheat growers in Latvia have used a variety of herbicides applied either in autumn or in spring. During the past five years the range of new herbicides intended for autumn application has increased. This could improve the possibilities to control the weeds in the autumn and so avoid the greater influence on grain yield.

MATERIALS AND METHODS

Field experiments were established in the Jelgava municipality in 2006–07 and 2007–08 in winter wheat. The evaluations of herbicide efficacy in the cereals followed EPPO Guideline PP 93 (2). Field trials were arranged in randomized blocks with 4 replicates. Plot size: 30 m² (3 m x 10 m).

In 2007 the sod-calcareous clay soil in the field had pH_{KCl} 7.2, an organic content of 2.3%; winter wheat cultivar 'Zentos' was sown on 05.09.06. The previous crop was winter oilseed rape. In 2008 the sod-calcareous loamy sand soil in the field had pH_{KCl} 6.1, an organic content of 1.8%; winter wheat cultivar 'Tarso' was sown on 09.09.07. The previous crop was winter wheat. In both fields minimal soil tillage was employed and a fertiliser top-dressing of 120–170 kg ha^{-1} was applied.

The herbicides used in the trials were: Alister Grande OD 217.5 (iodosulfuron-methyl-sodium 4.5 g L^{-1} + mesosulfuron-methyl 6 g L^{-1} + diflufenican, 180 g L^{-1}, Bayer CropScience); Hussar Activ OD 417 (iodosulfuron-methyl-sodium 10 g L^{-1} + 2,4-D 377 g L^{-1} as 2-ethyl-hehyl ester, Bayer CropScience); Monitor (sulfosulfuron 750 g L^{-1}, Monsanto); Arrat (tritosulfuron 25% + dicamba 50%, BASF). The surfactant Kemiwett Plus (alcohol ethoxylate) was added to the tank mix of Monitor and Arrat.

Herbicide treatments were applied using a knapsack sprayer "Gloria" with flat-fan nozzles XR TEEJET 8003VS, delivering a spray volume of 300 L ha^{-1} at a pressure of

300 kPa. Other plant protection measures were applied to the whole trial as necessary.

For the assessment for *Apera spica-venti*, the flowering panicles numbers were recorded at three random places within each plot with the aid of a 0.25 m² frame: when the growth stage of the crop was 86–87 BBCH on 25 July 2007 and 81–83 BBCH on 15 July 2008 (Tables 1, 2).

The total yield of grain from each plot was harvested by trial combine "Sampo 500", respectively on 8 August 2007 and 30 July 2008, recalculated to t ha^{-1} and given at 100% purity and 15% moisture content (Tables 1, 2).

To determine the relationship between the yields of winter wheat and the numbers of *Apera spica-venti*, the flowering panicles, the data from the untreated plots and the plots treated with herbicides were subject to analyses of variance and regression analysis. For statistical analysis the data were subjected to single factor analysis of variance using GenStat for Windows version 12. The treatment means were separated at the 95% probability level (LSD) using Student's *t*-test. Significant differences are stated next to the relevant figures in the tables: treatments marked with the same letter are not significantly different.

Weather conditions in 2006–2007 and 2007–2008. In autumn 2006 the herbicide treatments were applied on 26 September. During the third 10-day period of September the weather was unusually warm: the air temperature was more than 3 Cº above the long-term norm and without precipitation. The weather continued to be warmer than average throughout October and there was sufficient precipitation to provide very good conditions for weed growth after the autumn herbicide application (Figs 1, 2).

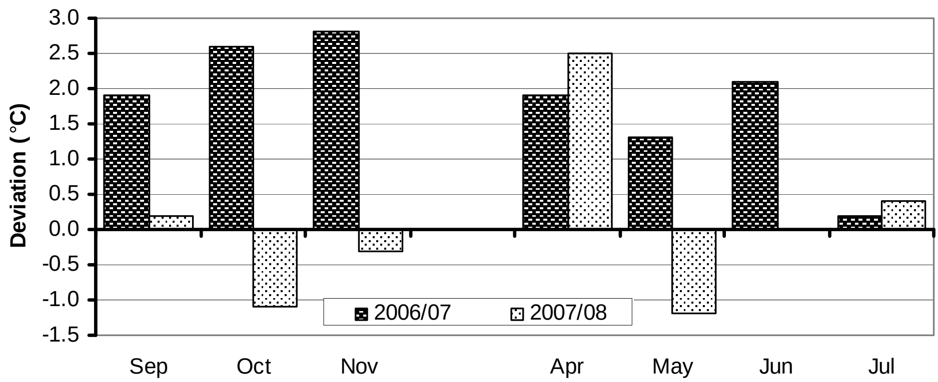

Figure 1. Deviations of monthly mean temperatures from long-term monthly means during growing seasons 2006–07 and 2007–08; data from Jelgava HMS.

In spring 2007 the weather around application time in the third 10-day period of April was unusually warm: the air temperature was more than 4 ºC above the norm, but precipitation was only 36% of the norm for that period. Two rainy days occurred before herbicide application (on 21 and 23 April) and that provided moist soil conditions. During the remainder of the vegetative period, up to the end of July, the weather was warmer than the long term-averages with sufficient precipitation in almost all months for good growth (Figs 1, 2).

The autumn 2007 herbicide treatments were applied on 28 September. The weather during the first and second 10-day periods of September was cooler than the long-term averages and some very rainy days occurred during the second 10-day period. Overall the daily mean temperature for the month was slightly above the long-term average and the precipitation was only 56.5 % of long-term average (Figs 1, 2). Around application time in spring 2008, during the second 10-day period of April, the mean daily temperature was higher than the long-term average and there was sufficient precipitation for plant growth. Overall, the weather during the vegetative period was drier than average which affected crop and weed emergence and development unfavourably.

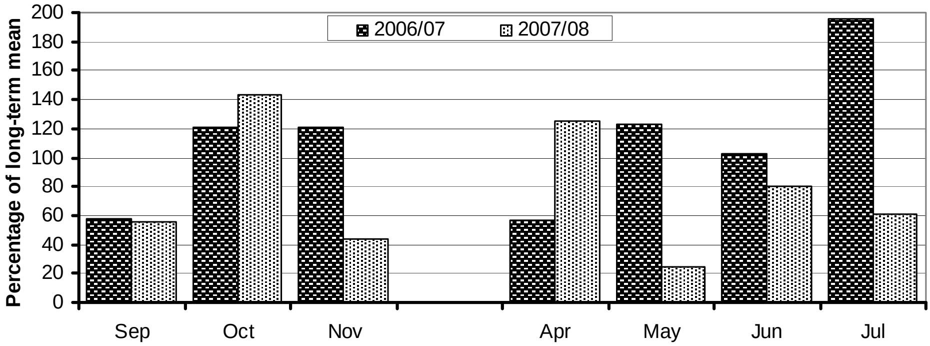

Figure 2. Total monthly precipitation as percentage of long-term monthly mean during growing seasons 2006–2007 and 2007–2008; data from Jelgava HMS.

RESULTS AND DISCUSSION

In autumn 2006 the emergence of the wheat plants was even and the plants were well developed, at 14–15 BBCH stage, when the autumn herbicide treatment was applied. The infestation of *Apera spica-venti* within the trial was 32 plants m^{-2}, up to 2 leaf stage (3–4 cm). In spring 2007 the winter wheat was at the end of the tillering stage (28–29 BBCH) when the spring herbicide treatments were applied and the density of *Apera spica-venti* in the untreated plots was 142 plants m^{-2}, mostly at 8 cm in height and well developed.

In autumn 2007 the winter wheat was at the 13–14 BBCH stage when the autumn herbicide treatment was applied. The growth stage of *Apera spica-venti* was up to 2 leaf stage and the infestation was very high: more than 430 plants m^{-2}. The spring herbicide treatments were applied on 16 April 2008 when the *Apera spica-venti* plants were at the tillering stage (12 cm in height) and the infestation was still very high: more than 424 plants m^{-2}.

In both of these winter wheat experiments dicot weed species were also recorded; the main species were: *Viola arvensis*, *Thlaspi arvense* and *Centaurea cyanus* as well as volunteer oilseed rape (*Brassica napus*). The biomass of the dicot weeds was only 20–30% of the total weed biomass. Most of the weed biomass was accounted for by *Apera spica-venti* and the high infestation of this grass species suppressed the growth of the dicot weeds.

The efficacy of the herbicide treatments in controlling *Apera spica-venti* was evaluated by counts of flowering panicles close to harvest time. All the herbicide treatments gave significant reductions in *A. spica-venti* panicle numbers compared with untreated (Tables 1, 2). Control of *Apera spica-venti* was satisfactory (95–96%) only in the plots where the herbicides had been applied in the autumn. The performance of the herbicides on *A. spica-venti* in reducing the numbers of flowering panicles was the same in both years.

Table 1. Numbers of *Apera spica-venti* and winter wheat yields, 2006–2007.

Treatments, dose per ha	Numbers of *Apera spica-venti* flowered panicles		Grain yield of winter wheat	
	number m^{-2}	decrease, %	kg ha^{-1}	± kg ha^{-1}
1. Untreated	190.0 a	-	1858 a	-
2. Alister Grande, 0.8 L*	8.3 c	96	5596 c	3738
3. Hussar Activ, 0.8 L **	79.3 b	58	3259 b	1401
4. Hussar Activ, 1.0 L **	68.0 b	64	2587 ab	729
5. Monitor,0.018 kg + Arrat, 0.2 kg**	46.7 bc	75	3324 b	1466
LSD 5%	58.06	-	1031.4	-

* in autumn 2006 ** in spring 2007

The average yield in the control plots was very low especially in 2007 (only 1858 kg ha^{-1}), because of the very high infestation of *Apera spica-venti*. Despite the moderate weed control in the herbicide treatments applied in spring, all treatments increased grain yield statistically significantly (Tables 1, 2). The increases given in the treatments where the herbicide had been applied in autumn were significantly higher than all but one of the increases where the herbicides had been applied in spring. The application with herbicides in spring could reduce the infestation of *Apera spica-venti*, but the crop stands were not as dense as in treatments where the herbicide application was made in the autumn. In weather conditions that were favourable for weed germination and development during the vegetative period, new weeds emerged and competed with the winter wheat and gave rise to problems with green weed material at harvest.

Table 2. Numbers of *Apera spica-venti* and winter wheat yields, 2007–2008.

Treatments, dose per ha	Numbers of *Apera spica-venti* flowered panicles		Grain yield of winter wheat	
	number m^{-2}	decrease, %	kg ha^{-1}	± kg ha^{-1}
1. Untreated	204.0 a	-	2606 a	-
2. Alister Grande, 0.8 L*	10.3 c	95	4732 c	2126
3. Hussar Activ, 0.8 L **	88.3 b	57	3576 b	971
4. Hussar Activ, 1.0 L **	84.0 b	59	3858 bc	1252
5. Monitor,0.018 kg + Arrat, 0.2 kg**	62.0 bc	70	3403 ab	797
LSD 5%	57.90	-	961.2	-

* in autumn 2007; ** in spring 2008

In both experiments there was a strong, significant, negative linear relationship between winter wheat yield and the numbers of *Apera spica-venti* flowered panicles (respectively r_{yx} = -0.73, P < 0.001; r_{yx} = -0.64, P < 0.01). The determination coefficients showed that 54% of the variations in the grain yield in 2007 and 41% in 2008 could be explained by the infestation of *Apera spica-venti* in the trial plots.

CONCLUSIONS

1. The application of herbicides in spring could not provide good control of *Apera spica-venti* up to harvest time when the infestation of this weed species at the application time was very high (more than 140 plants per m^2).

2. Application of appropriate herbicides in autumn for *Apera spica-venti* control provided satisfactory control up to harvest time in the following year.

3. The winter wheat crop in plots where herbicides were applied in the autumn was more even, denser and better developed than in plots where herbicides were applied in the spring. In the spring-treated plots the crops became thin and in open places, weed plants that were not controlled by the herbicides could regrow and develop well during the growing season up to harvest time.

4. For the best yield results herbicides should be applied in the autumn, especially when the weather is favourable for prolonged development of weeds and the infestations of competitive weed species like *Apera spica-venti* are very high.

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REFERENCES

Andreasen, C. & Stryhn, H. 2008 Increasing weed flora in Danish arable fields and its importance for biodiversity. *Weed Research*, **48**, (1), 1–9.

Bartels M. (2004) Ungräser sollten Sie im Herbst beseitigen. *Top Agrar* **9**, 50–55.

Brink, A. & Zollkau, A. 2004 Optimisation of grass weed control with Atlantis®WG in winter cereals. *Journal of Plant Diseases and Protection*. Supplement XIX, 637–646.

Hacker, E., Bieringer, H., Willms, Ort O., Koecher, H. & Kehne, H. 1999 Iodosulfuron plus mfenpyr-diethyl – a new foliar herbicide for weed control in cereals. *Proceedings of an international conference "The 1999 Brighton Conference – Weeds", Brighton, UK, November 15–18, 1999*. Vol. 3, pp. 737–746.

Melander, B., Holst, N., Jensen, P.K., Hansen, E.M. & Olesen, J.E. 2008 *Apera spica-venti* population dynamics and impact on crop yield as affected by tillage, crop rotation, location and herbicide programmes. *Weed Research*, **48**, (1), 48–57.

Pilipavičius V., Aliukonienė, I. & Romaneckas, K. 2010 Chemical weed control in winter wheat (Triticum aestivum L.) crop of early stages of development: I. Crop weediness. *Journal of Food, Agriculture & Environment*. 8(1); 206–209.

Schroeder, D., Mueller–Schaerer, H. & Stinson, C.S.A. 1993 A European weed survey in 10 major crop systems to identify targets for biological control. *Weed Research* **33**, (6) 519–525.

Streit, B., Rieger, S.B., Stamp, P. & Richner, W. 2003 Weed populations in winter wheat as affected by crop sequence, intensity of tillage and time of herbicide application in a cool and humid climate. *Weed Research*, 43, (1) 20–32.

Tottman, D.R., Ingram, G.H., Lock, A.A., Makepeace, R.J., Orson J., Smith J. & Wilson B.J. 1982 Weed control in Cereals. In: *Weed control handbook: Principles*. Roberts, H.A. (Ed): 7th ed. Blackwell Scientific Publications, Boston Melbourne, pp 268–291.

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The impact of a farm's annual cattle slurry yield on the options for moving the slurry from stable to plot: a simulation study

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Abstract. The economical efficacy is substantial on both occasions for feeding plants with nutrients and moving the manure from stables to the plots. The aim of the present research is to explain the limit values for the annual amount of slurry and average plot distance on a farm as conditions to decide in favour of a personal eco-friendly slurry distributor or custom equipment. In their previous researches, the authors have composed models to calculate slurry management costs for different technologies depending on plot distance, taking into account ammonia emissions. In the present study, simulations were made using the composed calculation models to compare slurry distribution costs for four slurry application technologies.

Calculations show that if the annual amount of slurry exceeds 4000 m^3, then for plot distance over 2 km, custom slurry distribution is cheaper than using the farm's own equipment. However, if the annual quantity of slurry exceeds 16,000 m^3, then the limit value for distance is 5 km.

If the annual amount of slurry is 4000 m^3, then full custom service is cheaper than the technology in which the farm's own slurry distributor and custom transportation is used. In the case of the annual amount of 16,000 m^3, it is less expensive to use the farm's own slurry distributor and custom transportation. In order to benefit from the use of the farm's own distributor the minimum value for annual slurry amount is 5600 m^3.

Key words: ammonia emissions, slurry application technology, plot distance, performance, operation costs, custom machines, annual slurry amount

INTRODUCTION

On the basis of environmental impacts in agricultural production, the following pollution subdivisions can be distinguished: point pollutants (animal farming, manure storages, etc) and diffuse pollution (e.g., pollution from manure distribution in the fields) (Dämmgen *et al*., 2007). Leakage of farmyard stores and runoff following slurry application to the land can lead directly to losses of organic matter, nutrients and pathogenic micro-organisms, with potential consequences for both stream ecology and human health (Naden *et al*., 2009). These diffuse losses have mainly been characterised in terms of nutrients (Vadas *et al*., 2007).

Ammonia volatilisation can be a major source of N losses from applied slurry (Lewis *et al*., 2003). Ammonia emission has been studied in several countries. The emission is magnified by higher air temperature during the spreading, wind (Misselbrook *et al*., 2005), higher pH, content of solid matter and ammonium nitrogen of the slurry (Mattila, 2006), as well as by high soil pH and temperature (Sommer *et al*., 2003; Misselbrook *et al*., 2005) and low soil moisture (Jokela & Meisinger, 2008).

Although gas emission, leaching of nutrients and odour have undesirable effects on the environment, the contribution of manure to plant nutrition and build-up of soil organic matter is considered to have a positive effect.

To utilise the nutrients contained in manure and minimise air pollution, it is essential to apply technology suppressing the gas emission from slurry distributed on the field. In the Defra (2006) project, the impact of different spreading devices on the ammonia emission was compared in the UK, Germany, Denmark and Finland. The average values of reduction of ammonia emission compared to technology where slurry was broadcast-spread and not incorporated from that research are as follows: trailing hose 32%, trailing shoe 60%, open slot injection 67%, closed slot injection 82% and deep injection 86%. By IPCC (2007) the ammonia emission factors for different application technologies are the following: 70% for broadcast spreading, without incorporation, 20% for spreading with a trailing hose, 10% for spreading with an open slot shallow injector and 1% for spreading with a closed slot. The effect of the use of slurry depends also on the time-lag between spreading and incorporation. The time-lag depends inter alia on the distance to the manure storage if incorporation is consecutive (one-man system) (Huijsmans and de Mol, 1999). Paudel *et al.* (2009) determined by a GIS-based model a least-cost dairy manure application distance for Louisiana's major dairy production area. A comparison between the dairy manure and commercial fertilizer application under three consistent rules – N, P_2O_5, and K_2O – revealed that the use of dairy manure is not economical after 30 km for N and 15 km each for P_2O_5 and K_2O.

Plant nutrient overloads can result from several forms of mismanagement, including over-fertilisation of crops (Gerber *et al.*, 2005). The objective should be to apply slurry to match the needs of the crop both in terms of amount and timing, attempting to minimise nutrient losses while maintaining adequate yields. Nutrient absorption by soil and plants is a complex of factors including soil, climate conditions, season and plant species (Lewis *et al.*, 2003).

In order to decrease excessive application of nutrients, it is not advisable to use more manure than the soil and yield properties allow. The herd size determines proportionally the area needed for distributing the manure produced by animals. However, the larger the areas, the longer are the average manure transportation distances (Tamm, 2009). The farm's annual slurry quantity and transportation distance as the selection criteria of slurry application technology should be explained. Schindler (2009) has published data for choosing the machines for the slurry delivery chain depending on those criteria in average production conditions of Germany with labour cost 16 € ha^{-1} and fuel price 1.45 € l^{-1}. In Estonia these values are 3.8 € ha^{-1} and 0.58 € l^{-1}, respectively. Thus, the German data are not applicable to Estonia and no literature is available with similar data for Estonia. The equipment for slurry application can be the farm's own or rented from a service provider. There are no data published about a farm's annual slurry quantity as a decision criterion to choose one's own or custom machinery.

Therefore, the present paper compares slurry distribution costs considering a farm's annual slurry quantity and average transportation distance in the case of four technological approaches for average Estonian production conditions:

1) incorporating disc device – the slurry is simultaneously distributed and mixed with soil;
2) incorporating disc device as in variant no. 1, but the slurry is transported to the

3) slurry spreading by trailing hose spreader plus a separate operation to incorporate the slurry to the soil; and
4) custom slurry distribution: slurry is transported by tank trucks to the plot and distributed with a self-propelling and incorporating slurry distributor.

The results from this study are considered to be targeted for slurry producers, to enhance their knowledge of the impact of the farm's annual slurry quantity and plot distance on the technological options.

MATERIALS AND METHODS

In calculations, it was presumed that manure comes from the farm's own production and the only costs arise from transportation and distribution. The calculation model is composed by the authors and has been previously published (Tamm & Vettik, 2008). The model contains components from the method, applied to evaluate options for exploitation of a plot considering costs depending on plot distance (Tamm, 2009). The prices of fuel and custom works used in calculations are from summer 2009. The prices of machines are collected from KTBL (2008).

Four simulated cases for slurry handling have been studied. A description of the technological sequence for slurry handling is as follows:

1) mixing – pumping from storage into the distributor tank – transporting with distributor to the plot – distribution and mixing with soil simultaneously;
2) mixing – pumping from storage into the custom truck tank – transporting with truck to the plot – pumping from the truck tank into the distributor tank – distribution and mixing with soil simultaneously;
3) mixing – pumping from storage into the distributor tank – transporting with distributor to the plot – distribution onto the soil with trailing hoses – separate operation to incorporate the slurry to the soil; and
4) mixing – pumping from storage into the custom truck tank – transporting with truck to the plot – pumping from truck tank into the custom distributor tank – the custom distributor tank distributes and mixes slurry with soil simultaneously.

Before slurry transportation and its distribution for slurry mixing and pumping 15 kW electrical device with performance 4.5 m^3 min^{-1} (price is 4605 €) is applied. From the observations of ERIA researchers, the slurry should be mixed the entire time the distribution lasts. On the plot, the distributor's own pump is used for over-pumping.

In all technological variants the distributor has a tank with 15 m^3 volume, fuel price is 0.58 € l^{-1} and labour cost is 3.8 € h^{-1}. The distributor used in variants 1 and 2 is equipped with a 4.5 m wide disc device (price of distributor is 52,560 €); tractor power is 158 kW (price is 102,560 €). The distributor used in variant 3 is equipped with a 12 m wide trailing hose spreader (price for whole system is 42,200 €) and the tractor engine power is 102 kW (price is 76,730 €). In variant 4, a custom self-propelled distributor equipped with a 4.5 m wide disc device is used with the engine power of 246 kW. The price of custom work with this distributor is 2.2 € m^{-3}.

If custom work is used only for transportation of the slurry to the field (variants 2 and 4), then the tanker lorry with initial cost 1.3 € m^{-3} is rented. If the distance exceeds 7 km, then 0.07 € m^{-3} per every extra km must be added to the initial cost.

In the 3rd technological variant a field-operation-unit containing a 158 kW tractor and a 4 m wide disk harrow (price is 31,950 €) to mix slurry with soil is used. The time span between slurry distribution and mixing with soil may not exceed 4 h.

Ammonia emission factors used for technologies are as follows: 20% for spreading with a trailing hose (variant 3) and 5% for incorporating the disc device (as the average value between values for spreading with an open slot shallow injector and for spreading with a closed slot) (variants 1, 2 and 4) (IPPC, 2007).

The annual work capacity for the spreader is 4000 m^3 and 16,000 m^3. The slurry rate was 40 m^3 ha^{-1} and the plot area was 20 ha for all technological variants. The operations are considered to be performed before the cereal is sown.

RESULTS AND DISCUSSION

Simulations were made using composed calculation models to compare slurry distribution costs for four slurry application technologies considering the farm's annual slurry quantity and distance to the plot. The results for technological variant 1 (farm's own soil mixing disc device) and 4 (custom slurry distributor) are shown in Fig. 1.

Fig. 1 indicates that if the annual quantity of slurry exceeds 4000 m^3, then for a plot distance over 2 km, custom slurry distribution is cheaper than the use of the farm's own equipment. Slurry management costs for 2 km and 4000 m^3 is 3.5 € m^{-3} both in the case of variant 1 and 4. However, if the annual quantity of slurry exceeds 16,000 m^3, then the limit value for distance is 5 km. For variant 1, slurry management costs for 5 km distance are 4.7 € m^{-3} and 3.5 € m^{-3} for annual slurry amounts 4000 m^3 and 16,000 m^3, correspondingly. The greater the annual amount of slurry, the cheaper is management of the slurry per m^3; Huijsmans *et al.* (2004) got similar results. However, a greater amount of slurry needs a larger distribution area, which requires a longer distance and a greater cost for slurry transportation.

Dr. Schindler (2009) has published data for a slurry distributor with a16 m^3 tank and a 6 m wide slot injector. If the distance to the plot is 2 km, the plot area is 10 ha, and the farm's annual quantity of slurry is 4,800 m^3, then the slurry distribution cost is 4.85 € m^{-3}. For 5 km, this cost is 6.43 € m^{-3}. The higher costs brought out by Schindler compared to our figures are probably induced by a more expensive distributor (it is wider and has a somewhat bigger tank, requiring a more powerful tractor), higher labour cost and fuel price.

The calculations show that distribution is cheaper (ca 0.64 € m^{-3}) in the case of the trailing hose spreader (variant No. 3), because of the greater work width and cheaper machine price; Huijsmans *et al.* (2004) and Schindler (2009) had analogous results. Considering the impact of the art of distribution of slurry on the loss of nitrogen by ammonia emission it is essential to incorporate slurry into the soil on arable land. The slurry incorporation performed for diminishing the ammonia emission is a separate operation with a cost of ca 25.6 € ha^{-1}. This result is the same as by using an incorporating spreader and, therefore, the results are not presented separately in the figure.

If the slurry distributor is used for slurry distribution only, then the custom tank lorry is used for transporting the slurry to the plot (variants 2 and 4); results are presented in Fig. 2. The eco-friendly slurry application equipment is expensive; therefore, it is most effective to use these machines for distribution, rather than for the transportation of slurry (Tamm, 2009). Thus, the separate vehicles with slurry tanks should be used to transport the slurry to the plot especially for longer distances. In Estonian conditions the maximum distance for transporting the slurry by distributor itself to the plot is about 4 km (Tamm & Vettik, 2008).

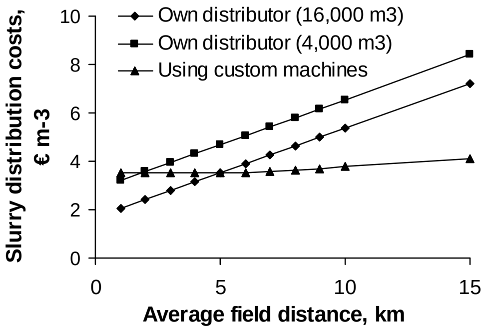

Figure 1. Slurry distribution costs in the case of farm's own distributor and using custom machines.

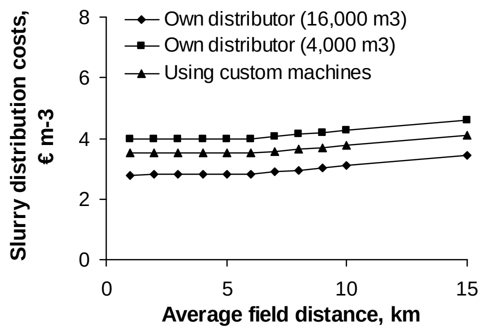

Figure 2. Slurry distribution costs if custom tank lorry is used for transportation and spreading is performed by farm's own distributor or custom distributor.

Figure 2 demonstrates that full custom service (variant 4) will be cheaper than the farms' own slurry distributor and custom transportation (variant 2), if the annual amount of slurry is 4000 m^3. If the annual amount is 16,000 m^3, then it will be less expensive to use the farm's own slurry distributor and custom transportation. For variant 2, slurry management costs for 5 km distance are 4.0 € m^{-3} and 2.8 € m^{-3} for annual slurry amounts of 4000 m^3 and 16,000 m^3, correspondingly. In order to benefit from the use of the farm's own distributor the minimum value for annual slurry amount is 5600 m^3 by our calculations. Sørensen *et al.* (2003) report that use of distributors with a large tank volume is rational when the annual slurry amount exceeds 9000 t. If that amount remains under 3000 t, it is not at all profitable to own a distributor; the custom distribution is cheaper.

CONCLUSIONS

Before investing in eco-friendly but expensive slurry distribution technology, the farmer has to calculate whether his farm has enough slurry to ensure a lower work price than custom service. The calculations show that, in the conditions used in our simulations, the minimum value for annual slurry amount is 5600 m^3 to own a distributor. We also found that the distribution cost in the case of a trailing hose spreader with an extra operation for soil mixing is equal to the distribution cost of incorporating a disc distributor. In the first case the additional time and labour should be taken into account for the soil-mixing operation. The ammonium emission is also somewhat higher than for other technologies compared in the present study. For longer distances to the plot, the farmer should consider hiring a custom tank lorry for slurry transportation, and the farm's own distributor should be used only for distribution on the plot.

REFERENCES

Dämmgen, U., Hutchings, N.J. 2007. Emissions of gaseous nitrogen species from manure management: A new approach. *Environmental Pollution* **154**, 488–497.

Defra. 2006. ADAS Research project *A Collation and Analysis of Current Ammonia Research* [WWW] http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=-More&Location=None&Completed=0&ProjectID=11440 (10.09.2009)

Gerber, P., Chilonda, P., Franceschini, G., Menzi, H. 2005. Geographical determinants and environmental implications of livestock production intensification in Asia. *Bioresource Technology* **96** (2), 263–276.

Huijsmans, J., Verwijs, B., Rodhe, L., Smith, K. 2004. Costs of emission-reducing manure application. *Bioresource Technology* **93**, 11–19.

Huijsmans, J.F.M., de Mol, R.M. 1999. A Model for Ammonia Volatilization after Surface Application and Subsequent Incorporation of Manure on Arable Land. *Journal of Agricultural Engineering Research* **74**, 73–82.

IPPC. 2007. Integrated Pollution Prevention and Control. Best Available Techniques for Intensive Rearing of Cattle. 2007. [WWW] http://www.ippc.envir.ee/docs/PVT/-BAT%20for%20Intensive%20Rearing%20of%20Cattle.pdf (02.09.2009).

Jokela, B., Meisinger, J. 2008. Ammonia Emissions From Field-applied Manure: Management For Environmental And Economic Benefits. In *Proc. Of The 2008 Wisconsin Fertilizer, Aglime & Pest Management Conference*, **47**. pp. 199–208.

KTBL 2008. Betriebsplanung Landwirtschaft 2008/09. 21. Auflage, 752 s. (in German)

Lewis, D.R., McGechan, M.B., McTaggart, I.P. 2003. Simulating field-scale nitrogen management scenarios involving fertiliser and slurry applications. *Agricultural Systems* **76**, pp 159–180.

Mattila, P.K. 2006. Ammonia emissions from pig and cattle slurry in the field and utilization of slurry nitrogen in crop production. Doctoral Thesis. MTT Agrifood Research Finland. 136 pp.

Misselbrook, T.H., Nicholson, F.A., Chambers, B.J. 2005. Predicting ammonia losses following the application of livestock manure to land. *Biosystems Technology* **96**, 159–168.

Naden, P.S., Old, G.H., Eliot-Laize, C., Granger, S.J., Hawkins, J.M.B., Bol, R., Haygarth, P. 2009. Assessment of natural fluorescence as a tracer of diffuse agricultural pollution from slurry spreading on intensely-farmed grasslands. *Water Research*. Article in press. doi:10.1016/j.watres.2009.11.038.

Paudel, K.P., Bhattarai, K., Gauthier, W.M., Hall, L.M. 2009. Geographic information systems (GIS) based model of dairy manure transportation and application with environmental quality consideration. *Waste Management* **29**, 1634–1643.

Schindler, M. 2009. Mit Gülletechnik Dünger sparen. *DLZ Agrarmagazin* 3, s 104–109 (in German).

Sommer, S.G., Génermont, P., Cellier, P., Hutchings, N.,J., Olsen J.E. 2003. Processes controlling ammonia emission from livestock slurry in the field. *European Journal of Agronomy* **19**, 465–486.

Sørensen, C.G., Brian H. Jacobsen, B.H., Sommer, S.G. 2003. An Assessment Tool applied to Manure Management Systems using Innovative Technologies. *Biosystems Engineering* **86** (3), 315–325.

Tamm, K. & Vettik, R. 2008. Case study: Economics of spring feeding in grassland. *Agronomy Research* **6**, 387–396.

Tamm, K. 2009. The dependency on the structure of machinery and the locality of plots on cereal farm work activities. Doctoral Thesis. Estonian University of Life Sciences. Tartu. 127 pp.

Vadas, P.A., Harmel, R.D., Kleinman, P.J.A. 2007. Transformations of soil and manure phosphorus after surface application of manure to field plots, *Nutrient Cycling in Agroecosystems* **77**, 83–99.

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Example:

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M. Kuusk[1] and K. Lepp[2]

[1]Institute of Agricultural and Environmental Sciences, Estonian Agricultural University, Kreutzwaldi 64, EE51014 Tartu, Estonia; e-mail:
[2]Institute of …

Abstract. In laboratory pupal…

Key words: *Galleria mellonella*, respirography, synergistic interaction

INTRODUCTION

In many countries rural inhabitants for insect control use various local plants (Smith & Jones, 1996; Brown et al., 1997; Adams, 1998).

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