Impact of slurry on the hop (*Humulus lupulus* L.) yield, its quality and N-min content of the soil

B. Čeh

Slovenian Institute of Hop Research and Brewing, Žalec, Slovenia

ABSTRACT

The aim of this investigation was to answer if cattle slurry can replace mineral fertiliser calcium ammonium nitrate for hop (*Humulus lupulus* L.) side-dressings, and if it is suitable to be applied after hop harvest, and also show its impact on N-min content of the soil. Cattle slurry was a more appropriate fertiliser for the second and the third hop side-dressings in the investigated years (2010–2012), which were characterised by a lower than average amount of rainfall and higher temperatures, especially in June and in the first half of July. Despite the lower amount of plant-available nitrogen in the cattle slurry (which contains also other nutrients and water), the yield of hop cones and the yield of alpha-acids were significantly higher, the NO_3^--N content in the cones was lower, and the N-min in the soil was lower. N-min analyses are urgent, at least in years with uncommon precipitation patterns, to make decisions about subsequent side-dressings. The weather conditions had a significant impact on the yield and the NO_3^--N content of the hop cones but not on the alpha-acid content.

Keywords: fertilisation; cattle slurry; mineral nitrogen; alpha-acid content; plant-available nitrogen

Hops (*Humulus lupulus* L.) are produced via intensive field-crop production methods using specific agricultural technology. Tendency to reduce production costs arises in years with lower prices and because fertiliser prices have increased recently. Nitrogen (N) side-dressing with cattle slurry is one of the alternatives for farms with their own cattle. The impact of slurry on the yield of different crops and their quality is well investigated and the conclusion is that when applied properly, liquid manure can be a partial or complete substitute for mineral fertilisers (Beauchamp 1986, Daudén and Quílez 2004), but no such results are provided for hop plants, a specific perennial field crop.

Estavillo et al. (1997) reported that unlike calcium ammonium nitrate (CAN), cattle slurry behaved as a slow-release fertiliser and that the supply of mineral N was still considerable when the fertiliser had been applied some time ago. On the other hand there is also a higher risk of N leaching losses from soils that receive cattle slurry regularly compared to soils that receive only mineral N fertilisers. Due to decomposition of the organic matter in the cattle slurry, N is also released from the organic matter in the years following the application of the slurry (Schröder et al. 2005).

The aim of this investigation was to answer some of the arising questions in hop production in the conditions of hop growing region in Slovenia, which represents 2.5% of world hop fields (IHGC 2013). We wanted to investigate if cattle slurry can replace mineral fertiliser CAN for hop side-dressings in terms of hop yield and its quality, if it is suitable to be applied after hop harvest and also its impact on N-min content of the soil, especially out of the growing season. The question was also what the impact of weather conditions on the yield of hops and its quality is.

MATERIAL AND METHODS

Experiment layout. Two field trials were conducted in 2010 and continued in 2011 and 2012 in

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Supported by the Ministry of Agriculture and Environment, in frame of task Technology in Hop Production and Processing.

Table 1. Timing of cattle slurry and mineral fertiliser calcium ammonium nitrate (CAN) applications for hop side-dressings, showing the treatment (A, B, C, D, E) and the amount applied

Treatment	Included in field experiment	N side-dressing			September
		1st	2nd	3rd	
A	(i) and (ii)		CAN; 70 kg/ha N	CAN; 50 kg/ha N	–
B	(i)		CAN; 70 kg/ha N	cattle slurry (26 m^3/ha)	–
C	(i)	CAN; 50 kg/ha N	cattle slurry (26 m^3/ha)	CAN; 50 kg/ha N	–
D	(i)		cattle slurry (26 m^3/ha)	cattle slurry (26 m^3/ha)	–
E	(ii)		CAN; 70 kg/ha N	CAN; 50 kg/ha N	cattle slurry[a] (26 m^3/ha)

[a] Not in 2012 because the soil was dry in summer and catch crop was not sown

the experimental fields of the Slovenian Institute of Hop Research and Brewing (IHPS) at Žalec (near Celje, Slovenia). A block trial (i) with treatments A, B, C and D was undertaken in one hop field, and another block trial (ii) with treatments A and E was undertaken in a hop field nearby (the size of one plot was 300 m^2 and 600 m^2, respectively), both with three replications.

Hop cv. Aurora. Aurora is a diploid hybrid with intense and pleasant hoppy aroma and contains 7.2–12.6% of alpha-acids.

Treatments and agro-technique used in the experiment. The treatments in the experiments were as shown in Table 1. N side-dressing was done three times: end of May, before the fast hop growth – around the 10th of June and at the beginning of flowering – in the first days of July. When cattle slurry was used for the second side-dressing, it was incorporated immediately at cultivation. When it was used for the third side-dressing, the slurry was used for hop defoliation at the same time and incorporated immediately at hop hilling up.

All the other agro-technical arrangements were the same for all treatments and according to good agricultural practice. The catch crop oilseed radish (*Raphanus sativus* L. var. *oleiformis*) was sown in 2010 and in 2011 after the last hop hilling up but not in 2012 because of a lack of precipitation. In 2010, the hop field was drip irrigated on the 12th of July and the 19th of July; approximately 25 mm of water was applied each time. There was no irrigation in 2011. In 2012, the hop field was irrigated once, using a hose-pull irrigator (on June 29), and 25 mm of water was applied.

Mineral fertiliser CAN (27% N) and cattle slurry. The granulated mineral fertiliser CAN contains 27% N, half in NO_3^--N and half in NH_4^+-N form, 2.7–3.3% Mg and 4.6–6.1% Ca (Petrokemija 2012). The nutrient content in cattle slurry can be highly variable and is affected by many factors, such as animal type, animal diet and dilution (Beauchamp 1986). Total N was analysed according to the ISO 11261 (1996) method. NH_4^+-N form of N was analysed according to the method of Jackson (1958). Despite the fact that the slurry was supplied by the same farmer on all the investigated years and for both N side-dressings, its nutrient content and dry matter content differed (Table 2). So, unexpectedly less N was applied with cattle slurry compared to CAN; for example, in 2011 in

Table 2. Cattle slurry characteristics concerning total N, NH_4^+-N, potassium, phosphorus and magnesium content

Year	Side-dressing	Dry matter content (%)	Total N applied with 26 m^3 (kg/ha N)	NH_4^+-N content in total N (%)	NH_4^+-N applied with 26 m^3 (kg/ha)	P	K	Mg	Ca
						(kg/26 m^3)			
2010	2nd	4	47	39	18	8	47	8	18
	3rd	8	81	42	34	10	75	10	29
2011	2nd	4	57	54	31	5	21	5	8
	3rd	4	57	55	32	5	24	5	8
2012	2nd	12	122	28	35	18	91	18	36
	3rd	9	109	31	33	21	115	23	49

treatment A 170 kg N/ha was applied, in treatment B 150 kg N/ha, in treatment C 130 kg N/ha and in treatment D 115 kg N/ha. But beside N cattle slurry contains also other nutrients and water (Table 2).

Soil and weather conditions. The experimental field contains heavy Eutric alluvial soils, with gleyic characteristics. It was composed out of 4 distinctive soil layers to the depth of 80 cm: A_1 horizon (from 0–20 cm); A_2 horizon (from 20–35 cm); AG_o horizon (from 35–50 cm), and G_oA horizon (from 50–80+ cm). The analysis revealed that the soil was on average (combining soil layers) silty clay loam, with 18.27% sand, 46.77% silt and 34.96% clay. In horizon A_2 and in all the other lower horizons structure was polyedric. At the start of the experiment, the soil of the upper horizon contained 1.9% of C, 20.1 mg P/100 g soil (Al method) and 18.8 mg K/100 g soil (Al method). The pH was 7.0.

The 40-year average precipitation from April to August (592 mm) was not reached in any of the investigated years (2010, 2011 and 2012) and the average temperature was higher than the 40-year average (16.4°C) (Figure 1). The warmest season was 2012 (almost 2°C warmer than the long-term average). The average seasonal temperature in 2010 and 2011 was similar (17.7°C and 17.9°C, respectively), and also the average precipitation amount (398 mm and 413 mm, respectively). During the hop growth season in 2010 the temperatures were high particular in the first 20 days of July, and there was only 9 mm of rainfall at that time. In the last 10 days of June, there was only 7 mm of rainfall. In the hop growth season in 2011 the largest rainfall deficit was recorded in August, while in the last ten days of May and in the first ten days of June there was more than average quantity of rainfall. In 2012 growth season there was 569 mm rainfall, out of which 100 mm fell in the time of harvest. Dry conditions prevailed from the autumn 2011 until March 2012. The lack of rainfall and high temperatures started again in June and continued until the harvest (Agrometeorological 2010, 2011 and 2012).

Mineral N in soil. Soil samples for mineral N (N-min – NO_3^--N and NH_4^+-N forms) detection were taken during the growth seasons and before the winter. The samples were immediately stored in a cool box and analysed for N-min according to DIN/EN (1998) method; measurement uncertainty was 1.1%. In the first two years (2010 and 2011) soil sampling of 0–25 cm soil layer was done with regard to the treatment; 7 subsamples were taken from each plot by a soil probe, collected together with regard to the treatment to form a sample (one soil sample per treatment). In 2012, the soil was sampled to a depth of 60 cm (0–30 cm and 30–60 cm) and plot by plot. At each sampling 20 to 25 subsamples were taken from each plot by a soil probe, collected together to form a sample (one soil sample per plot).

Experiment evaluation. When the hop cv. Aurora reached technological maturity (last dec-

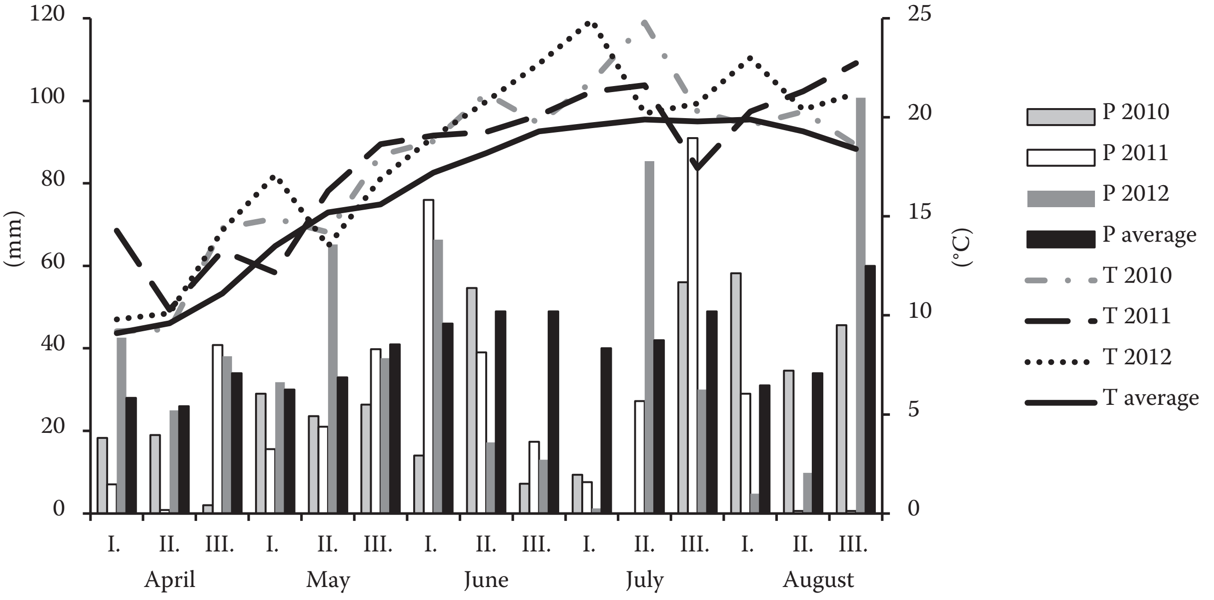

Figure 1. Average 10-days temperatures (T, °C) and precipitation amount (P, mm) in the hop growth seasons in 2010, 2011 and 2012 compared to the 40-year average (average) at the investigated location Žalec near Celje, Slovenia

ade in August) the crop was harvested plot by plot manually in the field without outer rows, and the cones were harvested by a harvester afterwards. The yield of the hop cones in each plot was estimated, samples of cones were taken. Determination of the moisture and alpha-acid content was performed using the standard Analytica-EBC (1998 and 2000) methods. The NO_3^--N content of the hop cones was analysed according to DIN/EN (1998) method. The results were statistically processed by the computer programs Excel (Microsoft Corportaion, 2013) and Statgraphics (Centurion, Statpoint), and differences among treatments were detected by the Duncan's multiple range test ($P < 0.05$) for both field experiments (i) and (ii).

RESULTS AND DISCUSSION

N-min in soil. At the conduction of the experiments, in a hop field with experiment (ii) where treatments A and E were set in a block trial, there was 35 kg/ha less N-min compared to the field with the block trial (i) with treatments A, B, C and D (Table 3).

At the beginning of July, before the third hop side-dressing in 2010, in field experiment (i), there was a higher N-min quantity in the soil treated with CAN as a second side-dressing (treatments A and B) compared to the treatments where the cattle slurry was used (treatments C and D), with an increase as high as 70 kg/ha N-min in the former (Table 3). A part of the difference could be explained by the cattle slurry containing less N compared to CAN. More N from the fertilisers probably accumulated in the soil than usual due to the lack of precipitation; there was a relatively high amount of N-min in the soil that is common before the third hop side-dressing (as much as 208 kg/ha N-min in the top 0–25 cm of the soil). However, after the harvest, there was no more than 40 kg/ha N-min in the upper layer (0–25 cm) of the soil in all the treatments.

In spring 2011, between 50 and 60 kg/ha of N-min were present in the upper layer of the soil (0–25 cm) in all the treatments, except for treatment C, where 112 kg/ha N-min was measured at that time (Table 3). Higher N-min content in treatment C could be a consequence of N mineralisation of the organic matter in the cattle slurry applied in the previous year or a consequence of the sampling. Again, as in the previous year, before the third side-dressing, there was higher amount of N-min in the soil where CAN was used for the second side-dressing (treatments A and B) compared to the treatments where the cattle slurry was used (treatments C and D). However, the difference in that year was lower compared to the previous year. The presence of sufficient moisture in the soil at the time of the second side-dressing in 2011 obviously affected processes in the soil differently compared to the previous year when soil was dry at that time. As shown in Table 3, the values were much lower

Table 3. The results of the soil analysis of NO_3^--N and NH_4^+-N in the upper 25 cm of soil in 2010 and in 2011 with regard to the treatments (A, B, C, D in the field experiment (i) and A and E in the field experiment (ii)) and the date of sampling

Date of sampling	Field experiment	Treatment	NO_3^--N	NH_4^+-N
			(kg/ha)	
9th June 2010	(i)	A, B, C, D	154	25
	(ii)	A, E	115	29
Before 3rd side-dressing (8th July 2010)	(i)	A	150	15
		B	198	10
		C	126	12
		D	138	11
After harvest (13th September 2010)	(i)	A	24	20
		B	20	18
		C	24	14
		D	20	16
Before 1st side-dressing (12th May 2011)	(i)	A	28	39
		B	32	25
		C	28	84
		D	24	27
	(ii)	A	32	22
		E	40	23
Before 3rd side-dressing (5th July 2011)	(i)	A	71	12
		B	59	12
		C	24	11
		D	16	8
	(ii)	A	63	11
		E	63	10
After harvest (22nd September 2011)	(i)	A	16	12
		B	12	3
		C	12	3
		D	12	4
	(ii)	A	16	4
		E	16	4

compared to the previous year, from 24 to 83 kg/ha N-min.

After the harvest in 2011, the N-min content of the soil with the various treatments was similar, around 15 kg/ha N-min (Table 3). A slight deviation was observed with treatment A where CAN was used for all three N side-dressings (28 kg/ha N-min).

From the results in Table 3, it can be seen that it is not justifiable to measure only the NO_3^--N form of N in the soil to determine the plant available N content in the soil. The NH_4^+-N form is usually low, however, sometimes it can be high and have a large impact on the amount of plant available N.

In the spring of 2012 (Table 4) and before the second hop side-dressing (data not shown), there was no significant difference among treatments in soil N-min (0–60 cm). The consequence of dry autumn, winter, beginning of spring and summer (Figure 1) was seen in the relatively high N-min values throughout the season in 2012. Depending on the treatment, already in spring there was 78 to 92 kg/ha N-min (Table 4).

Before the third hop N side-dressing, at the end of June in 2012, there were significant differences in the soil N-min in both investigated soil layers (0–30 cm and 30–60 cm) and in both investigated N forms (NO_3^--N and NH_4^+-N). There was, on av-

Table 4. The results of the soil analysis of plant available N (NO_3^--N and NH_4^+-N) at a depth of 0–30 cm and 30–60 cm in 2012 with regard to the treatments (A, B, C, D in field experiment (i) and A and E in the field experiment (ii)) and the date of sampling

Date of sampling	Field experiment	Treatment	NO_3^--N (kg/ha)		NH_4^+-N (kg/ha)		NO_3^--N + NH_4^+-N (kg/ha)
			0–60 cm				
28th April	(i)	A	73^{aa}		15^{a}		88^{a}
		B	66^{a}		12^{a}		78^{a}
		C	72^{a}		19^{a}		91^{a}
		D	73^{a}		19^{a}		92^{a}
	(ii)	A	72^{a}		12^{a}		84^{a}
		E	76^{a}		15^{a}		91^{a}
			0–30 cm	30–60 cm	0–30 cm	30–60 cm	0–60 cm
Before 3rd side-dressing (27th June)	(i)	A	243^{b}	125^{b}	12^{ab}	15^{c}	395^{b}
		B	262^{b}	122^{b}	11^{ab}	18^{c}	414^{b}
		C	138^{a}	87^{a}	20^{c}	16^{c}	260^{a}
		D	153^{a}	93^{a}	13^{b}	14^{bc}	274^{a}
	(ii)	A	250^{b}	111^{ab}	11^{ab}	10^{ab}	381^{b}
		E	333^{c}	125^{b}	8^{a}	8^{a}	489^{c}
After harvest (29th August)	(i)	A	139^{bc}	104^{bc}	10^{a}	11^{a}	264^{b}
		B	115^{b}	92^{bc}	8^{a}	9^{a}	224^{b}
		C	139^{bc}	86^{b}	8^{a}	9^{a}	241^{b}
		D	73^{a}	52^{a}	9^{a}	8^{a}	142^{a}
	(ii)	A	139^{bc}	116^{bc}	8^{a}	9^{a}	270^{b}
		E	165^{c}	123^{c}	8^{a}	8^{a}	294^{b}
Before winter (26th November)	(i)	A	< 14	< 15	< 8	< 6	< 43
		B	< 14	< 14	< 5	< 7	< 40
		C	< 14	< 14	7	< 4	< 39
		D	< 15	< 17	10	8	< 50
	(ii)	A	< 14	25	8	9	< 56
		E	< 14	22	8	10	< 54

The same letter in the column inside one term of sampling indicates that there is no significant difference between treatments (Duncan test; $P = 0.05$)

erage, as much as 200 kg N/ha in NO_3^--N form in the upper 30 cm layer and 107 kg/ha in the layer underneath (30–60 cm) in the field experiment (i). There was significantly higher N-min (0–60 cm) in the treatments where CAN was used for the second side-dressing (treatments A and B) compared to the treatments where cattle slurry was used (treatments C and D) in both investigated layers. With slurry 35 kg/ha less N was applied in the second side-dressing in that year and it is also possible that some N was lost from the slurry at the time of application, while leaching was probably not a factor because there was very low precipitation in June and in the first 10 days of July. In the field experiment (ii) there was a significantly higher amount of NO_3^--N in the treatment E compared to the treatment A (presumably from the mineralisation of organic matter applied with cattle slurry in the two previous years).

After the harvest in 2012, there was still a high N-min content of the soil of all the treatments (on average, 218 kg/ha N-min in the field experiment (i) and 282 kg/ha in the field experiment (ii) (Table 4). Presumably due to the lack of precipitation and high temperatures in that year, N accumulated in the soil after each side-dressing and also after mineralisation and the absorption by the hop plants was low (and consequently also the yield; Table 5). In field experiment (i) there was significantly lower N-min in both soil layers (0–30 cm and 30–60 cm) in treatment D where cattle slurry was used twice, compared to the other treatments (A, B, C), but the quantity of N-min was still very high (142 kg/ha). Problems occurred later when there was substantial precipitation in autumn, and a huge amount of N-min was leached away before winter (there was no catch crop in 2012) from the upper 60 cm soil layer. At the time of the last soil sampling on November 26, 2012, there was only 39 to 56 kg/ha N-min (0–60 cm) in the soil (Table 4), namely.

Hop yield and its quality. Table 5 shows the yield of the hop cones and the quality of the yield with regard to the various treatments and investigated year in field experiment (i). Despite the application of a lower amount of N, there was a significantly higher yield of hop cones and alpha-acid yield with the treatments C and D (Table 5) (cattle slurry was used for the second hop side-dressing in both treatments). Obviously, in the weather conditions that prevailed in June and in the first half of July in the investigated years (low amount of precipitation and higher than average temperature; Figure 1), the cattle slurry was more effective compared to the CAN mineral granular fertiliser. Beside N slurry contains also water and other nutrients.

The form of fertiliser for the hop side-dressing had no significant effect on the alpha-acid content of the hop cones. No significant treatment × year interaction was found for any of the investigated parameters. Dauden and Quilez (2003) compared a control with mineral fertilisation and pig slurry in irrigated Mediterranean typical xerofluvent soil and found no significant differences in the aboveground biomass, corn yield and N plant uptake between the different fertilisation schemes. However, similar to our experiment, they reported that NO_3^--N concentrations in the soil solution were higher for the control treatment than for the slurry

Table 5. Yield of hop cones (dry matter), alpha-acid content in hop cones, yield of alpha-acid and NO_3^--N content in hop cones at cv. Aurora in the field experiment (i) with regard to the treatment (A, B, C and D) and investigated year (2010, 2011 and 2012)

		Yield (kg/ha dry matter)	Alpha-acid content (% dry matter)	Yield of alpha-acid (kg/ha)	NO_3^--N (mg/100 g dry matter)
Treatment	A	1255^{ab}	8.9^{a}	112^{a}	1385^{b}
	B	1234^{a}	9.3^{a}	115^{ab}	1396^{b}
	C	1392^{bc}	9.3^{a}	130^{bc}	1228^{a}
	D	1414^{c}	9.3^{a}	133^{c}	1179^{a}
Year	2010	1504^{b}	9.4^{a}	142^{b}	1489^{b}
	2011	1511^{b}	9.2^{a}	139^{b}	1232^{a}
	2012	956^{a}	9.0^{a}	86^{a}	1170^{a}

The same letter in the column inside one factor indicates that there is no significant difference between treatments (Duncan test; $P = 0.05$)

treatments. Berenguer et al. (2008) conducted field experiments with pig slurry combined with mineral N and found that maize yield, biomass and other related yield parameters differed from year to year.

In both field experiments (i); Table 5 and (ii); data not shown), there was a significantly lower yield of cones, a lower yield of cones per plant and a lower alpha-acid yield in 2012 compared to 2010 and 2011. The significant impact of year on the yield of hop cv. Aurora was reported also by Bavec et al. (2003). The alpha-acid content of the cones did not depend on the year, whereas the NO_3^--N content was significantly higher in 2010 compared to 2011 and 2012.

The application of cattle slurry after the hop harvest (for the catch crop oilseed radish) did not have a significant impact on yield of hops and its quality in the following years, but a slightly negative impact was detected (field experiment (ii); data not shown).

To conclude, N-min analyses are urgent, at least in years with uncommon precipitation patterns, to obtain information on the quantity of plant available N already present in the soil of hop fields. The results of such analyses are needed to make decisions about subsequent side-dressings and to avoid situations that lead not only to environmental burdening but also to money wasted on fertilisers and bad management. When there is a lack of precipitation in the time of the second or the third side-dressing cattle slurry is more recommended compared to granular mineral N fertiliser with regard to the hop yield. When using cattle slurry for hop side-dressing, chemical analysis of the slurry is recommended before its application because the nutrient content of this type of fertiliser varies greatly. It is important to ensure that the N quantity is not too high and that the amount of P and K is subtracted from the mineral fertiliser rate.

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Received on January 21, 2014
Accepted on April 25, 2014

Corresponding author:

Dr. Barbara Čeh, Slovenian Institute of Hop Research and Brewing, Cesta Žalskega tabora 2, 3310 Žalec, Slovenia
e-mail: barbara.ceh@ihps.si