Hop yield evaluation depending on experimental plot area under different nitrogen management

F. Bavec[1], B. Čeh Brežnik[2], M. Brežnik[3]

[1]*Faculty of Agriculture, University of Maribor, Slovenia*
[2]*Biotechnical Faculty, University of Ljubljana, Slovenia*
[3]*Agrosaat d.o.o., Ljubljana, Slovenia*

ABSTRACT

Numerous agricultural and associated ecological effects such as mineral nitrogen fertilising influence the yield of hop (*Humulus lupulus* L.) cones and its quality. Using a wide spacing of plants (in our case 2.6 × 0.8 m) we want to answer a hypothetical question about an appropriate number of test plants per plot vs. experimental plot area. The aim of this study was to compare the effect of different rates of mineral nitrogen, fertiliser combinations and their nitrogen split application on hop yield evaluated from different plot areas (micro trial: 30 plants per plot; macro trial: 320 plants per plot). Hop yield varied significantly between treatments, plot areas, years and interactions (year × treatment, plot area × treatment) (all at $P \leq 0.01$). Cone yield in a micro trial was higher in all treatments in comparison with yield in a macro trial. In spite of common intensive fertilisation the appropriate fertilising combination and mineral N rate can influence the yield. Target nitrogen rate of 160 kg mineral N/ha (at the level from 40.0 to 62.5 kg nitrate N/ha in soil depth to 0.3 m) and cheaper combination of calcium-ammonium nitrate (50 kg N/ha) at the beginning of vegetation plus urea (110 kg N/ha) for top dressing can be recommended. On plot areas of each size and each year all treatments showed similar trends of fertilising effect on yield. In spite of higher yield in the micro trial and lower coefficient of variation in comparison with the macro trial, the results proved that a risk of incorrect yield analysing in macro trials is very low for field experiments.

Keywords: *Humulus lupulus* L.; hop; nitrogen; experimental plot; yield

JCR Web of Science (from 1970 to 2001) sorted by the key word *Humulus lupulus* L. vs. hop includes only 14 papers dealing with hop production and associated environmental research. There is no data on development of experimentation research, fertilisation and environment pollution by hop production. One reason for the lack of experiments may be a scientifically appropriate size of samples (how to evaluate yield from large experimental plots, small number of plants per plot, people do not like harvesting by hand and difficulties by combining yield in experiments, etc.).

The yield of hop cones depends on production system and weather conditions, especially on nutrient supply. Mineral nitrogen (N) fertilising is one of treatments that can influence the quantity and quality of hop cones. Different nitrogen uptake from 108 to 193 kg N/ha by hop yield of 2 t was found in Yugoslavia (Kišgeci et al. 1984). Taking into account the differences in climatic conditions and production system, in Germany 270 kg N/ha in more than one split dose is recommended (Rossbauer and Zwack 1983), in Italy 150–200 kg N/ha in three split doses (Biacardi and Wagner 1989), in the Czech Republic 65–130 kg N/ha (Maťátko 1985), in England 150–225 kg N/ha and in the USA 160 kg N/ha (Neve 1991). In non arable, under grassland hop plantations in Slovenia 300 kg N/ha is recommended (Wagner 1986), in cultivated plantations total supply of N per year should not be higher than 180–200 kg N/ha, split in three doses, the first one of 40–60 kg N/ha (Anon IHP 1980–1981, Majer 1997) in the last decade of May. In spite of high available nitrogen soil reserves, worse soil structure and inefficiency of high mineral N rates that can even cause a decrease in yield and alpha-acid content, the use of mineral N fertilisers has not decreased in Slovenia; it is common to use 250 kg N/ha per year and more where this rate does not include N, contained in defoliants (approximately 50 kg N/ha) for side sprout elimination (Majer 1994, 1998a).

In general, the plot size for agronomic trials is larger than that for variety trials. It is because of the size of machinery used and due to the border effects caused in part by the use of machinery (Petersen 1994). Considering a wide spacing of hop plants (for example 1.6 × 1.4 m, 1.8 × 1.3 m, 2.0 × 1.0–1.2 m, 2.4 × 0.7–1.05 m, 2.6 × 0.7–0.8 m, i.e. 3250 to 5950 plants/ha), different number of analysed plants per plot, plant variability and less (small plots) or more simplified evaluation from large plots with common combine harvesting there arises a hypothetical question about an appropriate number of test plants vs. experimental plot area. Reasons for unequal results and experimental error from a comparison of micro and macro trials are differences in soil uniformity, potential voids and the effect of plot border area that increases yield with plot area decreasing. On the other hand, it is known (Korić 1952, Petersen 1994) that the plot area is in inverse relation with experimental error.

The aim of this study is to compare the effect of different mineral nitrogen fertilising management on the yield of hop cones, when evaluated on small plots (micro trial) in comparison with large plots (macro trial) harvested by a combine similarly like in production hop gardens. Trends of cone yield on micro and macro plots are analysed with respect to treatments and years. In spite of common micro plot preference, comparable results concerning the experimental plot area in practice are discussed.

MATERIAL AND METHODS

Hop field trials were conducted near Žalec in Savinja valley, Slovenia (46°19'N, 15°2'E) in the complex of 8.76 ha with hop plants 260 × 80 cm apart (5200 plants/ha) in 1998–1999. Research was carried out on medium early aromatic cultivar Aurora, crossbred between Northern brewer and TG (Slovene hop of unknown origin). It ripens between August 23 and 30. Genetic yield potential is 3.2 t/ha (Kralj et al. 1991).

The field area of 8.76 ha was split in five blocks, four of them were used as blocks for a macro trial and one was used for a micro trial. For both sizes of experimental plots (micro and macro trial), there were six treatments arranged in a randomised block system (Table 1) in four replications. The borders of micro trial plots were surrounded by border plants, in the macro trial middle rows (out of five) were evaluated, so the border influence was eliminated. The examined macro trial contained 320 plants (planting places) per plot, the examined micro trial contained 30 plants per plot.

In the first experimental year at the beginning of vegetation six soil samples (to depth 0.3 m) were analysed for nitrogen (NO_3^-) content by HPLC method. On average 53.4 kg NO_3-N/ha was calculated for soil dry matter, ranging from 40.0 to 62.5 kg NO_3-N/ha. The high soil nitrate content was affected by high nitrogen rates applied a year before. In the years before the experiment a mineral N rate was 250 kg/ha that did not include defoliant ammonium-sulphur and urea-ammonium nitrate with additional 50 kg N/ha used before harvest.

Every year fertilisation and side dressing were done by machines in the macro trial and by hand in the micro trial. Phosphorus and potassium rates amounted to150 kg P_2O_5/ha and 200 kg K_2O/ha.

At each planting place vs. plant there were two strings, on each string three bines were trained. In both years preventive spraying against *Pseudoperonospora humuli* was done by Ridomil MZ (8% metalaksil + 40% copper). Crop management (plant cutting, soil cultivation, filling up plants after cutting, plant protection) was done by machines and there were no important differences between the years (Table 2).

Hop plants were harvested by combine WOLF 280 with working capacity of 280 hop bines per hour. Harvested yield (hop cones) was weighed and samples from each plot were dried three days at a temperature of 70°C. The yield was calculated per hectare. Nitrogen expenses were calculated for each fertilising combination; fertiliser prices in Slovenia (calculated in EUR/USD) were taken as they were in March 2002.

Field trial (block design) was analysed as a factorial experiment (micro and macro trial, six fertilising combinations, years).

During the experiment the precipitation sum in the vegetation period (from April to August) ranged from 543 mm in 1998 to 896 mm in 1999 (30 years average is 595 mm). During the vegetation period 1998 rainfall was lower than hop needs (600 mm), there was a moisture deficit (159 mm) at stages of intensive growth from the first pair of leaves to final height (BBCH stage11–39, Rossbauer et al. 1997). High temperature and moisture deficit from beginning of

Table 1. Nitrogen rates, fertilising combinations and costs for target yield of 2000 kg dry cones/ha

	Fertilising combinations and N rates	Nitrogen costs*/ha
A	CAN[a] (50 kg N/ha) + urea[b] (80 + 70 kg N/ha), (total 200 kg N/ha, target 1 kg N for 10 kg dry cones), three split rates	113.1 EUR vs. 98.5 USD
B	CAN (50 + 40 kg N/ha) + urea (70 kg N/ha) + defoliation with UAN[c] (40 kg N/ha) included in N balance (total 200 kg N/ha, target 1 kg N for 10 kg dry cones), three split rates + defoliation	124.6 EUR vs. 108.5 USD
C	CAN (50 kg N) + urea (110 kg N/ha) in one split for top dressing (160 kg N/ha, 0.8 kg N for 10 kg dry cones), two split rates	93.3 EUR vs. 81.2 USD
D	CAN (50 + 40 kg N/ha) + urea (70 kg N/ha), (160 kg N/ha, target 0.8 kg N for 10 kg dry cones), three split rates	104.4 EUR vs. 90.9 USD
E	CAN (50 kg N/ha) + urea (70 kg N/ha) + UAN (20 + 20 kg N/ha) used twice and included in N balance (160 kg N/ha, target 0.8 kg N for 10 kg dry cones), three split rates + defoliation	93.6 EUR vs. 81.5 USD
F	control without N fertilising	0

[a]CAN (calcium-ammonium nitrate, 27% N) used at the beginning of vegetation, [b]urea (46% N) used for top dressing,
[c]UAN (urea-ammonium nitrate, 52% N) used for defoliation
* costs based on average of March 2002 in Slovenia

Table 2. Some important data on the production system used in field experiments in experimental years

	1998	1999
Manual cut (BBCH 08)	March 25	March 27
First training of runners (BBCH 25–25)	April 30	May 2
Fertilisation with P and K (BBCH 01)	1st decade of March	3rd decade of February
First top dressing (BBCH 29)	May 13	May 10
Second top dressing (BBCH 32)	June 2	June 1
Third top dressing, depending on treatment (BBCH 36)	July 9	July 7
Defoliation with UAN, depending on treatment (BBCH 75)	June 17	June 22
Harvest date (BBCH 89) and final evaluation of the yield	August 26–27	August 27–28

florescence to technological maturity (BBCH 51–89) may decrease growth and yield quantity and quality (Friškovec 1999, Majer 1998b, 1999), and it is taken account of experimental vegetation periods that were warmer in both years (average of each is 17.8°C) than the long term average (16.4°C), and in both years temperatures increased and decreased drastically (even by 10°C).

Analysis of variance (ANOVA) for factorial experiments was conducted using STATGRAPHIC©*Plus* 4.0, and significance of factor effects was determined at $P \leq 0.05$ (*) and 0.01 (**), respectively. Tukey's tests were used to determine significant differences between data means (at $P \leq 0.05$) of fertilisation treatments (6) × plot size (2) × 2 years. In the case of significant interaction the influence on yield data was described by interaction plot.

RESULTS AND DISCUSSION

Hop yield varied significantly between treatments, sizes of experimental plot, years (Table 3) and interactions (year × treatment, plot size × treatment; other interactions did not differ significantly) (all at $P \leq 0.01$; the results were identical by Tukey's *HSD* and Duncan's tests).

The yield in control treatment (F, without nitrogen fertilisation) was significantly lower than in other treatments. The yield increased in treatment B, but in other treatments (A, C, D, E) it was significantly higher and did not differ significantly ($P \leq 0.05$). Because there were no differences in the yields of treatments A, C, D and E, but they were significantly higher than yields in treatments B and F, combination C represents the lowest expenses

Table 3. Significance of the effects of different N fertilising combinations evaluated for two years in micro (30 plants per plot) and macro (320 plants per plot) plots on hop cone yield and their variability

Factor	Significance level for yield (kg/ha)	Coefficient of variation	Standard deviation
Fertilising treatment (F)	**		
Plot size (P)	**		
Year (Y)	**		
P × F	**		
F × Y	**		
P × Y	n.s.		
F × P × Y	n.s.		
Fertilising treatment			
F (control without nitrogen fertilisation)	1377 c	23%	316
B (200 kg N, CAN + CAN + urea + UAN)	1782 b	10%	177
E (160 kg N, CAN + urea + UAN + UAN)	1862 a	7%	131
A (200 kg N, CAN + CAN + urea)	1868 a	7.8%	146
D (160 kg N, CAN + CAN + urea + UAN)	1874 a	7.2%	136
C (160 kg N, CAN + urea)	1900 a	7%	132
Plot size			
Micro (30 plants/plot)	1.881 a	10.1%	189
Macro (320 plants/plot)	1.673 b	16.4%	275
Years			
1998	1.861 a	10.8%	201
1999	1.693 b	16.6%	281

** indicate significance at $P \leq 0.01$, n.s. indicates that treatment effects were not significant

a, b, c means within a column followed by different letters are significantly different at the 95% confidence level (Tukey's test)

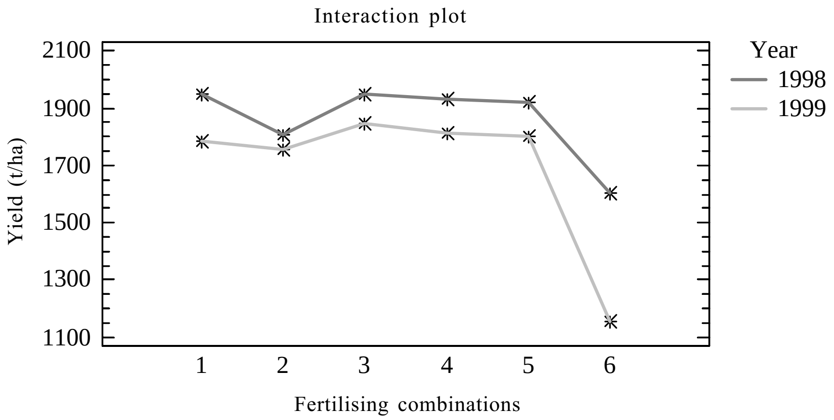

Figure 1. Hop yield affected by interaction of fertilising combinations (Table 1) × year

for nitrogen fertilisers (81.2 USD/ha) and only two instead of three top dressings.

On average the yield in macro trial was significantly lower compared to the yield in micro trial and ranged from 5.3% to 38.3% between years, but the interaction between plot size and year was not significant, similarly like plot size × nitrogen treatments × year interaction. The yield in treatment A was higher in micro than in macro trial by 10.6 or 11.1%, in B by 17.9 or 14.2%, in C by 8.5 or 8.1%, in D by 6.8 or 7.0%, in E by 5.3 or 9.9%, and the yield in treatment F (control plot) by 28.4% and 38.8% in 1998 and 1999, respectively. Standard error of macro trial was higher (0.0396) compared to micro trial (0.0273), consistently with Petersen (1994).

Yield was significantly influenced by fertilising combination × plot size interaction. Figure 1 shows that a large difference between micro and macro plot exists only in control treatment, where the effect could be obtained by a difference of available nitrogen from soils due to differences analysed before the start of trials. Similar trends were also found between fertilising combination and experimental year (Figure 2).

Coefficients of variation for yields in all treatments of macro trial were higher compared to the micro trial (Table 3); and they were all lower than 11%, except three of them.

However, the differences in soil nitrogen (from 40.0 to 62.5 kg NO_3-N/ha) at the start of experiment were not an important barrier for result deviations when comparing macro and micro trial. At other sites, potential errors (especially affected by plant variations) in micro plots multiplied errors due to calculation of average data per hectare. Higher yield in micro plots could also be obtained by difficult control of light interception per low number of plants on the micro plot border area than in macro plots.

The yield was significantly higher in 1998 than in 1999; 1998 was a record year in the whole Savinja valley; it was a dry year but hop plantations were irrigated when it was needed and temperatures were high through the whole vegetation (temperatures above 30°C occurred soon after May 10). In 1999 there were large temperature fluctuations. However, in both years the growing conditions were not optimal for hop production. Higher yields in 1998 compared to 1999 were probably due to low nitrogen residues after the first year of experimentation.

CONCLUSIONS

The yield of hop cones was higher in micro trial in comparison with yield in macro trial, but the treatments showed similar trends of fertilising effect on the yield in all treatments. In spite of the difference 22.5 kg NO_3-N/ha depending on plot location, higher yield in the micro trial and lower coefficient of variation as well as standard error

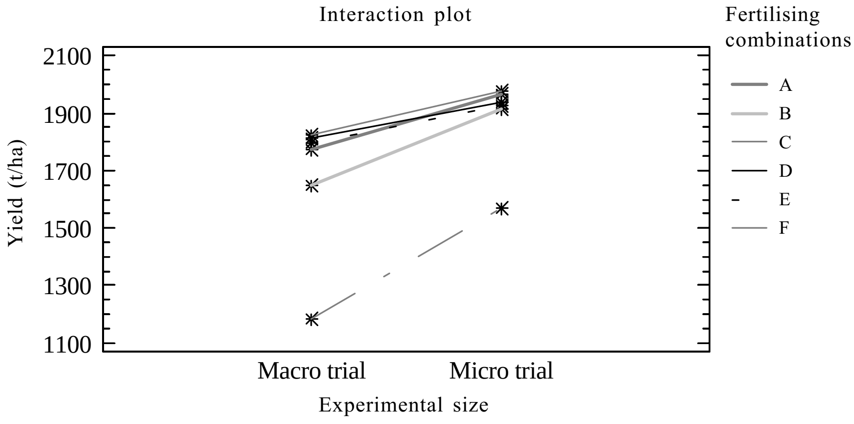

Figure 2. Hop yield affected by interaction of plot size × fertilising combinations (Table 1)

compared to the macro trial, the results proved that a risk of incorrect yield evaluation in macro trials is very low for field experiments. Target nitrogen rate of 160 kg mineral N/ha (split in two identical rates) using a cheaper combination of calcium-ammonium nitrate at the beginning of vegetation plus urea for top dressing can be recommended.

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ABSTRAKT

Hodnocení výnosu chmele v závislosti na velikosti pokusné plochy při rozdílném hnojení dusíkem

Výnos hlávek chmele (*Humulus lupulus* L.) a jeho kvalitu ovlivňuje řada zemědělských a ekologických faktorů, jako např. hnojení minerálním dusíkem. Při širokém sponu výsadby (v našem případě 2,6 × 0,8 m) jsme ověřovali hypotetickou otázku týkající se vhodného počtu pokusných rostlin na plochu versus velikost pokusné plochy. Cílem této práce bylo porovnání vlivu rozdílných dávek minerálního dusíku, kombinací hnojiv a jejich dělené aplikace na výnos chmele z plochy rozdílné velikosti (mikropokus: 30 rostlin na plochu; makropokus: 320 rostlin na plochu). Výnos chmele významně kolísal v jednotlivých variantách, při různých velikostech plochy, v jednotlivých letech a interakcích (ročník × varianta, velikost plochy × varianta) ($P \leq 0,01$). Výnos chmelových hlávek byl ve všech variantách vyšší v mikropokusu ve srovnání s makropokusem. Při intenzivním hnojení může výnos ovlivnit vhodná kombinace hnojiv a dávka minerálního dusíku. Pro hnojení na list lze doporučit cílovou dávku dusíku 160 kg minerálního N/ha (při hladině od 40,0 do 62,5 kg dusičnanového N/ha v půdní hloubce do 0,3 m) a méně nákladnou kombinaci dusičnanu vápenato-amonného (50 kg N/ha) na začátku vegetace s přídavkem močoviny (110 kg N/ha). Všechny velikosti ploch a každoročně všechny varianty vykazovaly obdobný trend vlivu hnojení na výnos. Přes vyšší výnos v mikropokusu a nižší koeficient variace ve srovnání s makropokusem výsledky dokládají, že pro polní pokusy je riziko nesprávné analýzy výnosu v makropokusech velmi nízké.

Klíčová slova: *Humulus lupulus* L.; chmel; dusík; pokusná plocha; výnos

Corresponding author:

Prof. Dr. Franc Bavec, Faculty of Agriculture, University of Maribor, Vrbanska 30, 2000 Maribor, Slovenia
tel.: + 386 22 505 830, fax: + 386 22 296 071, e-mail: franci.bavec@uni-mb.si