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# Yield, Quality and Nitrogen Use of Forage Maize under Different Nitrogen Application Rates in Two Boreal Locations

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**Abstract:** Research focusing on the nitrogen (N) application and N use of forage maize (*Zea mays* L.) in the boreal region is either limited or non-existent. The aim of this study was to investigate the response of yield, quality and N recovery efficiency ($N_{RE}$) of forage maize to an increase in the N application rate and different climatic conditions in two locations in Finland. The field experiment was conducted in southern (Helsinki; 60° N) and central (Maaninka; 63° N) Finland in 2019 and 2020. Dry matter (DM) yield, forage quality and $N_{RE}$ were determined for N application rates of 100, 150 and 200 N kg ha$^{-1}$. The DM yield was similar to all studied N application rates. Moreover, there were no marked differences in the studied forage quality traits or the $N_{RE}$ following the N application rates. However, the $N_{RE}$ of maize was generally low at 45%. The current study recommends a N application rate of 100–150 N kg ha$^{-1}$ for forage maize in the boreal region. There is no need to increase the N application from current recommendations since climate conditions seem to limit the growth, development and $N_{RE}$ of forage maize. The observed low $N_{RE}$ of forage maize warrants further research in the future.

**Keywords:** nitrogen fertiliser; nitrogen recovery; forage production; forage quality; maize silage



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## 1. Introduction

Forage maize (*Zea mays* L.) is a whole-crop forage used as roughage, fed mainly to dairy and beef cattle. In the boreal region, forage maize cultivation is limited due to a short growing season, low temperature and frosts in the early and late growing season [1,2]. However, the interest of farmers in the cultivation of forage maize in the boreal region has increased steadily for several reasons: forage maize is harvested only once a year; it has a high dry matter (DM) yield with good nutritive value; and new, early maturing cultivars have been released to the market in recent decades [3,4].

Maize was originally a tropical cro [5]. It has an optimum temperature of approximately 28–34 °C [6,7]. Formerly, forage maize was grown in Europe in areas where the daily mean temperature of the growing season (May–September) is above 17 °C [2]. During recent decades, the northern border of maize cultivation has moved up to around latitude 60° N [8], where the mean temperature of the growing season is 14–15 °C. In the future, maize will benefit from rising temperatures and a prolonged growing season, and thus the area of maize cultivation is expected to increase, for example, in the north of Europe [9–11].

Forage maize cultivation in Finland and the whole boreal region was the target of extensive investigation activities in the 1970s and 1980s [1,12,13]; however, interest in forage maize investigation diminished during the following decades [4,8,14,15]. Consequently, the number of studies concerning nitrogen (N) application of forage maize in the boreal region is limited. The current recommendations for N application to forage maize in Finland are based on Kara and Pulli's [12] proposals to apply less than 150 N kg $ha^{-1}$ to forage maize. However, maize cultivars released to the market in the 2000s and 2010s accumulate more N than earlier released cultivars [16,17]. Therefore, the N fertilisation demand may also be increased after the studies conducted in the 1970s and 1980s. Additionally, forage maize is often considered to require abundant fertilisation due to the high DM yield, which results in high nutrient removal from a field [3,18]. Nevertheless, maize recovers normally less than 50% of applied N [19], which is similar to other cereals [20]. In addition, maize does not necessarily fulfil its potential to recover N under marginal climatic conditions [21], such as 55–65° N latitudes, where the mean temperature of the growing season ranges roughly from 10 to 15 °C. Investigation of N recovery efficiency ($N_{RE}$; % of applied mineral N recovered by a plant) is important since the low recovery of N increases the risk of N losses and N-related emissions to air and water [22,23] However, the $N_{RE}$ of forage maize has not previously been investigated in the boreal region.

In general, N application enhances maize leaf growth and delays leaf senescence, hence increasing the photosynthetic capacity [24] and leading to increased biomass growth and ear DM content [19,25]. The increased ear DM content relates to starch synthesis since, during ear development, carbohydrates are transported from the leaves and stalk to the ears, where carbohydrates are converted to starch [19,24]. In theory, the starch content of maize ears increases with an increasing N application rate, because N enhances the supply of photosynthetic assimilates used in starch synthesis [24]. However, N application has shown a non-existent, low or unclear effect on the starch content and other quality traits of forage maize [12,21,26,27].

The aim of this study was to evaluate the effect of increasing N application rates and annually differing climatic conditions on the yield, quality and $N_{RE}$ of forage maize grown in two boreal locations (southern and central Finland).

## 2. Materials and Methods

### 2.1. Experimental Site

Field experiments were conducted in 2019 and 2020 at Viikki Research Farm (60°13′ N, 24°02′ E, 8 m.a.s.l.), University of Helsinki, Helsinki, Finland, and at the Maaninka Research Station (63°09′ N, 27°18′ E, 90 m.a.s.l.), Natural Resources Institute Finland, Maaninka, Kuopio, Finland. According to the World Reference Base [28], the soils were typically Luvic Gleysols and Luvic Stagnosols at the Viikki Research Farm, and Dystric Regosols at the Maaninka Research Station.

The field topsoil (0–25 cm) in Helsinki had a pH of 6.1, a soil organic matter (SOM) content of 8.8% and 9.8%, phosphorus (P) content of 11 and 5.9 mg $L^{-1}$ and potassium (K) content of 180 and 260 mg $L^{-1}$ in 2019 and 2020, respectively. The field topsoil in Maaninka had a pH of 6.4, a SOM content of 3.8% and 4.4%, P content of 64 and 22 mg $L^{-1}$ and K content of 160 and 210 mg $L^{-1}$ in 2019 and 2020, respectively.

### 2.2. Plant Material and Experimental Design

Plots were fertilised before sowing. In Helsinki, the N application rates were 100, 150 and 200 N kg $ha^{-1}$ (100N, 150N and 200N), and the reference treatment was 10 N kg $ha^{-1}$ (N 27%; Premium Typpi 27, Belor Agro, Salo, Finland; N-P: 12-23; Starttiravinne, Yara Suomi, Espoo, Finland). The reference treatment exceeded 0 N kg $ha^{-1}$ for technical reasons since the P fertiliser product used included N and because the P application rate was the same for all plots, 20 kg $ha^{-1}$ (N-P: 12-23; Starttiravinne, Yara Suomi, Espoo, Finland). The K application rate in Helsinki was 170 kg $ha^{-1}$ in 2019 (K 25%, Patentkali, K + S Minerals and Agriculture, Kassel, Germany) and 150 kg $ha^{-1}$ in 2020 (K 50%, Kaliumsuola, Yara Suomi, Espoo, Finland). In Maaninka, the N application rates were 150 and 200 N kg $ha^{-1}$ (150N and 200N) and the K application rate was 6 kg $ha^{-1}$ in 2019 (N-K: 27-1; YaraBela

Suomensalpietari, Yara Suomi, Espoo, Finland) and 82–109 kg ha$^{-1}$ in 2020 (N-K: 22-12; YaraMila NK2, Yara Suomi, Espoo, Finland). Phosphorus was not applied in Maaninka.

Maize, cv. P7326 (FAO 180; Pioneer Hi-Bred International, Johnston, IA, USA), was sown in Helsinki on 17 May 2019 and 26 May 2020, and in Maaninka, on 16 May 2019 and 28 May 2020. Seeds were sown 5 cm deep with plastic film mulch (Oxo-Biodegradable Clear Mulch Film, Samco Agricultural Manufacturing, Limerick, Ireland), and the seeding density was 90 000 seeds ha$^{-1}$.

In Helsinki, plots consisted of four 10 m long rows, totaling 30 m$^2$. In Maaninka, the plots were 5 m long, totaling 15 m$^2$. At both locations, the field experiments were arranged in a randomised complete block design (RCBD) with 3–4 replicates.

In Helsinki, all plots were sprayed when seeding, with pendimethalin (Stomp, 5 L ha$^{-1}$, active ingredient (a.i.) 400 g L$^{-1}$; BASF, Ludwigshafen, Germany), and approximately 3 weeks after seeding, with thifensulfuron-methyl (Harmony 50SX, 10–15 g ha$^{-1}$, a.i. 500 g kg$^{-1}$; DuPont, Wilmington, NC, USA) and rimsulfuron (Titus WSB, 30–50 g ha$^{-1}$, a.i. 250 g kg$^{-1}$; DuPont, Wilmington, NC, USA). Herbicides were not used in Maaninka.

### *2.3. Plant Sampling, Sample Preparation and Yield Measurements*

In Helsinki, plants were harvested on 8 October 2019 and 14 October 2020. In Maaninka, the harvests were conducted on 3 October 2019 and 15 October 2020. Before harvests, plants from 1 m of either of the two inner rows were cut 15 cm above the soil surface. Sampled plants were weighed and counted, and the height of each plant was measured, after which the plants were divided into ears and vegetative plant mass (stalk and leaves). The ear growth stage was defined visually using R stages [29]. In Helsinki, ears and vegetative plant mass were chopped with pruners and a knife, dried separately for 5–7 days at 100 °C and weighed. In Maaninka, ears and vegetative plant mass were chopped with a laboratory chopper, after which 200–300 g samples were dried separately for 3–4 days at 50 °C and weighed. The DM content (g kg$^{-1}$) of ears and vegetative plant mass was calculated as (dry mass (g)/fresh mass (g)) × 1000. The ear proportion of DM yield (%) was calculated as ear dry mass (g)/(ear dry mass (g) + vegetative plant dry mass (g)) × 100.

After sampling, in Helsinki, two inner rows of plots were harvested with a chopper (JF FH 1300, Kongskilde Agriculture, Albertslund, Denmark) approximately 15 cm above the soil surface. The harvested fresh yield was weighed immediately, and a subsample of approximately 3 kg was collected and stored at 5 °C. In Maaninka, two inner rows were cut at 15 cm above the soil surface with a hand sickle, the harvested fresh yield was weighed, and a subsample of 3–4 kg was collected and chopped with a laboratory chopper.

Part of the collected subsample was further used for the analysis of DM content (g kg$^{-1}$). In Helsinki, the DM content was measured from a sample of 150–200 g by drying for 48 h at 100 °C. In Maaninka, an approximately 200 g sample for measuring the DM content was dried for 3–4 days at 50 °C. The DM yield (DM Mg ha$^{-1}$) was calculated as fresh yield (Mg ha$^{-1}$) × DM content (g kg$^{-1}$)/1000.

In Helsinki, an approximate 200 g sample was dried in an oven for 1 h at 103 °C and 48 h at 50 °C for chemical analysis. In Maaninka, a sample dried for measuring the DM content was also used as a chemical analysis sample. Chemical analysis samples from both locations were ground into a fine powder (1 mm sieve; Sakomylly KT-3100, Koneteollisuus, Helsinki, Finland).

### *2.4. Chemical Analyses*

For analysis of the water content of the ground chemical analysis sample, 1.0 g of the sample was first dried for approximately 16 h at 105 °C and weighed. Then, the sample was combusted in a muffle furnace (Heraeus Thermicon T, Heraeus, Hanau, Germany) for 6 h at 550 °C and weighed to analyse the ash content. For determination of the N mass fraction (g kg$^{-1}$ DM), a 200 mg sample was combusted according to the Dumas method [30] in a

C/N analyser (FP828, LECO, St. Joseph, MI, USA). Crude protein (CP; g $kg^{-1}$ DM) was calculated by multiplying the N mass fraction by a protein ratio of 6.25.

Starch (g $kg^{-1}$ DM) was analysed from a 100 mg sample according to Hall [31] with a commercial kit (Total Starch Assay Kit (AA/AMG), Megazyme, Wicklow, Ireland) spectrophotometrically (Shimadzu UV-1800, Shimadzu, Kyoto, Japan). Neutral detergent fibre (NDF; g $kg^{-1}$ DM) was determined from a 100 mg sample with Van Soest et al.'s [32] method using an NDF analyser (either Fibretherm FT 12, Gerhardt, Königswinter, Germany or Heraeus Thermicon T, Heraeus, Hanau, Germany). Sugar (g $kg^{-1}$ DM) was analysed with Somogyi's [33] method spectrophotometrically. In vitro organic matter (OM) digestibility (g $kg^{-1}$) was analysed with the pepsin-cellulase method [34] using modifications by Nousiainen et al. [35]. The D-value (digestible organic matter in the DM; g $kg^{-1}$ DM) was calculated as (1000 − ash) × OM digestibility [36].

### 2.5. Nitrogen Yield and Recovery Efficiency

Nitrogen yield (N kg $ha^{-1}$) was calculated as N mass fraction (g $kg^{-1}$ DM) × DM yield (DM Mg $ha^{-1}$). Nitrogen recovery efficiency ($N_{RE}$; % of applied mineral N recovered by a plant) was calculated according to Varvel and Peterson [37] as:

$$N_{RE} = (N_{YieldFert} - N_{Yield10} - 10)/N_{Rate} \times 100, \quad (1)$$

where $N_{YieldFert}$ is the N yield of plots with 100–200N application rate, $N_{Yield10}$ is the N yield of reference treatment plots (10 N kg $ha^{-1}$) and $N_{Rate}$ is the N application rate (N kg $ha^{-1}$). $N_{RE}$ was calculated for Helsinki only.

### 2.6. Weather

The weather data used were from the Finnish Meteorological Institute [38]. The results are presented in Table 1. The effective temperature sum (°Cd) for maize was calculated with a base temperature of 10 °C [39] as:

$$\text{Effective temperature sum} = \sum (((temp_{max} + temp_{min})/2) - 10), \quad (2)$$

where $temp_{max}$ and $temp_{min}$ are the daily maximum and minimum temperatures (°C), respectively. If $temp_{max}$ was >30 °C, it was set to equal 30 °C and if $temp_{min}$ was <10 °C, it was set to equal 10 °C. The effective temperature sums accumulated between sowing and harvest were 861 °Cd and 857 °Cd in Helsinki and 668 °Cd and 709 °Cd in Maaninka, in 2019 and 2020, respectively.

**Table 1.** Monthly mean temperatures and precipitation during the growing seasons in 2019 and 2020 and the long-term mean (1991–2020) in Kaisaniemi (60°18′ N, 24°94′ E, 3 m.a.s.l.), Helsinki, and Maaninka (63°14′ N, 27°31′ E, 91 m.a.s.l.), Kuopio [38].

| | **Temperature (°C)** | | | | | | **Precipitation (mm)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Helsinki** | | | **Maaninka** | | | **Helsinki** | | | **Maaninka** | | |
| | 2019 | 2020 | 1991–2020 | 2019 | 2020 | 1991–2020 | 2019 | 2020 | 1991–2020 | 2019 | 2020 | 1991–2020 |
| May | 10.3 | 9.6 | 10.4 | 8.6 | 7.8 | 9.1 | 62 | 53 | 38 | 66 | 32 | 49 |
| June | 17.3 | 17.9 | 14.9 | 16.1 | 18.0 | 14.4 | 16 | 75 | 60 | 39 | 76 | 71 |
| July | 17.5 | 16.7 | 18.1 | 15.2 | 15.8 | 17.1 | 73 | 83 | 57 | 14 | 76 | 85 |
| August | 17.3 | 17.1 | 16.9 | 15.1 | 15.4 | 15.1 | 82 | 77 | 81 | 41 | 36 | 66 |
| September | 12.2 | 13.8 | 12.3 | 9.6 | 11.0 | 10.0 | 77 | 55 | 56 | 44 | 122 | 55 |
| October | 6.2 | 9.3 | 6.6 | 2.7 | 6.3 | 3.9 | 102 | 64 | 73 | 80 | 92 | 55 |

### 2.7. Statistical Analyses

Statistical analyses were conducted using the SAS 9.4 (SAS/STAT Software, SAS Institute, Cary, NC, USA) MIXED procedure. One replicate of 100N, 150N and 200N was excluded from the statistical analyses in Helsinki in 2020 due to the unauthorised collection of ears by the public from some of the plots. Results from the reference treatment plots were used only for calculating the N yield and $N_{RE}$. All results from the reference treatment plots were excluded from the statistical analyses due to a lack of practical importance of the N application rate of 10 N kg $ha^{-1}$. An analysis of variance was done separately for both locations with a model including the N application rate and year as fixed factors, and replication within a year as a random factor. The level of significance used was $p < 0.05$. Pairwise comparisons within a year for the results from Helsinki were conducted using Tukey-Kramer's adjustment for multiple comparisons.

## 3. Results

### *3.1. Forage Yield and Dry Matter Content*

The DM yield did not respond to the N application rate or the year in Helsinki, and there was no interaction between the N application rate and year (Table 2). Therefore, the DM yield in Helsinki was approximately 17.7 Mg $ha^{-1}$. In Maaninka, the N application rate did not affect the DM yield, and the interaction between the N application rate and the year was not significant. However, the DM yield was 56% higher in 2020 than in 2019 (20.6 vs. 13.2 Mg $ha^{-1}$).

**Table 2.** Yield, yield dry matter (DM) content and nitrogen yield of forage maize in the field experiment conducted in Helsinki and Maaninka, Finland, in 2019 and 2020. Data shown are means. Standard error of the means is given in parentheses ($n$ = 6–10).

| Location | | Yield (DM Mg $ha^{-1}$) | DM Content (g $kg^{-1}$) | N Yield (N kg $ha^{-1}$) |
|---|---|---|---|---|
| Helsinki | N Application Rate | | | |
| | 100N | 17.0 (0.57) | 314 (7.8) | 171 (9.1) |
| | 150N | 18.3 (0.54) | 312 (7.4) | 190 (8.6) |
| | 200N | 17.7 (0.57) | 321 (7.8) | 195 (9.1) |
| | Year | | | |
| | 2019 | 17.7 (0.57) | 351 (8.1) | 219 (9.4) |
| | 2020 | 17.7 (0.62) | 280 (9.0) | 152 (10.5) |
| | *p*-value | | | |
| | N | 0.202 | 0.589 | 0.083 |
| | Y | 0.944 | 0.003 | 0.005 |
| | N × Y | 0.531 | 0.705 | 0.815 |
| Maaninka | N Application Rate | | | |
| | 150N | 16.0 (0.95) | 212 (5.4) | 217 (13.3) |
| | 200N | 17.8 (0.95) | 214 (5.4) | 239 (14.4) |
| | Year | | | |
| | 2019 | 13.2 (0.95) | 199 (5.4) | 165 (14.4) |
| | 2020 | 20.6 (0.95) | 226 (5.4) | 291 (13.3) |
| | *p*-value | | | |
| | N | 0.214 | 0.815 | 0.289 |
| | Y | <0.001 | 0.005 | <0.001 |
| | N × Y | 0.628 | 0.645 | 0.416 |

DM = dry matter; N = nitrogen application rate (N kg $ha^{-1}$), Y = year, N × Y = interaction between the nitrogen application rate and the year.

In Helsinki and Maaninka, the DM content of the yield did not respond to the N application rate, and the interaction between the N application rate and the year was not significant (Table 2). Nevertheless, in Helsinki, the DM content was 20% lower in 2020 than in 2019 (280 vs. 351 g $kg^{-1}$). Annual differences were observed also in Maaninka, where the DM content was 14% higher in 2020 than in 2019 (226 vs. 199 g $kg^{-1}$).

### *3.2. Forage Quality*

In Helsinki, forage CP content responded to the N application rate in both years, since the CP content was 9–10% higher for 200N compared with 100N (Table 3). Additionally, the CP content was 45% higher in 2019 than in 2020 for all N application rates studied (77 vs. 53 g $kg^{-1}$ DM). However, in Maaninka, the CP content of the yield was not affected by the N application rate or the year and thus was approximately 85 g $kg^{-1}$ DM.

**Table 3.** Quality of forage maize yield in the field experiment conducted in Helsinki and Maaninka, Finland, in 2019 and 2020. Data shown are means. Standard error of the means is given in parentheses ($n$ = 3–4).

| Location | Year | N Application Rate | CP | NDF | Starch | Sugar | Ash | D-Value |
|---|---|---|---|---|---|---|---|---|
| | | | g kg$^{-1}$ DM | | | | | |
| Helsinki | 2019 | 100N | 74 (2.0) a | 469 (10.1) | 229 (24.3) | 50 (5.0) ab | 44 (2.1) | 662 (4.5) |
| | | 150N | 77 (1.7) ab | 471 (8.5) | 220 (21.1) | 33 (4.5) a | 45 (1.8) | 663 (3.9) |
| | | 200N | 81 (2.0) b | 435 (10.1) | 246 (24.3) | 59 (5.0) b | 45 (2.1) | 671 (4.5) |
| | 2020 | 100N | 51 (2.0) a | 469 (9.9) | 190 (24.3) | 74 (5.2) a | 56 (2.1) | 637 (4.5) |
| | | 150N | 53 (2.0) ab | 474 (9.9) | 151 (24.3) | 95 (5.2) b | 56 (2.1) | 631 (4.5) |
| | | 200N | 56 (2.0) b | 477 (9.9) | 178 (24.3) | 98 (5.2) b | 55 (2.1) | 629 (4.5) |
| | | $p$-value | | | | | | |
| | | N | 0.007 | 0.211 | 0.482 | 0.003 | 0.986 | 0.696 |
| | | Y | <0.001 | 0.169 | 0.010 | <0.001 | <0.001 | <0.001 |
| | | N × Y | 0.872 | 0.093 | 0.776 | 0.002 | 0.906 | 0.198 |
| Maaninka | 2019 | 150N | 81 (3.6) | 531 (15.3) | 24 (17.9) | 200 (25.5) | 39 (2.5) | 587 (14.8) |
| | | 200N | 83 (3.6) | 541 (15.3) | 38 (17.9) | 158 (25.5) | 38 (2.5) | 574 (14.8) |
| | 2020 | 150N | 88 (3.6) | 456 (15.3) | 98 (17.9) | 193 (25.5) | 49 (2.5) | 647 (14.8) |
| | | 200N | 89 (3.6) | 456 (15.3) | 124 (17.9) | 168 (25.5) | 45 (2.5) | 653 (14.8) |
| | | $p$-value | | | | | | |
| | | N | 0.570 | 0.761 | 0.269 | 0.213 | 0.297 | 0.805 |
| | | Y | 0.134 | <0.001 | 0.006 | 0.946 | 0.013 | <0.001 |
| | | N × Y | 0.840 | 0.763 | 0.728 | 0.741 | 0.515 | 0.532 |

CP = crude protein, DM = dry matter, D-value = digestible organic matter in dry matter, NDF = neutral detergent fibre; N = nitrogen application rate (N kg ha$^{-1}$), Y = year, N × Y = interaction between the nitrogen application rate and the year. Means marked with different letters (a, b) differ significantly ($p$ < 0.05) from each other within a year in Helsinki.

In Helsinki and Maaninka, forage NDF and starch contents did not respond to the N application rate or the year (Table 3). In Helsinki, the NDF content did not vary significantly between years at approximately 466 g kg$^{-1}$ DM. However, the starch content observed in Helsinki was 34% higher in 2019 than in 2020 (232 vs. 173 g kg$^{-1}$ DM). As for Maaninka, the NDF and starch contents were both affected by the year. In 2019, the NDF content was 17% higher than in 2020 (536 vs. 456 g kg$^{-1}$ DM). Moreover, the starch content was considerably higher in 2020 than in 2019 (111 vs. 31 g kg$^{-1}$ DM).

Forage sugar content responded to the N application rate in Helsinki, and there was also an interaction between the N application rate and the year (Table 3). In 2019, 150N resulted in lower sugar content than 200N. In 2020, 100N had a lower sugar content than 150N and 200N. Generally, the sugar content in Helsinki was 89% higher in 2020 than in 2019 (89 vs. 47 g kg$^{-1}$ DM). In Maaninka, the N application rate or year did not affect the sugar content; hence, the sugar content averaged 180 g kg$^{-1}$ DM.

The N application rate had no effect on the forage ash content or D-value in Helsinki or Maaninka, although the ash content and D-value differed annually (Table 3). In Helsinki, the ash content was 24% higher in 2020 than in 2019 (56 vs. 45 g kg$^{-1}$ DM) and the D-value was slightly higher in 2019 than in 2020 (665 vs. 632 g kg$^{-1}$ DM). In Maaninka, the ash content observed in 2020 was 21% higher than in 2019 (47 vs. 39 g kg$^{-1}$ DM). The D-value in Maaninka was 12% higher in 2020 than in 2019 (650 vs. 581 g kg$^{-1}$ DM).

### *3.3. Nitrogen Yield and Recovery Efficiency*

The N application rate did not affect the N yield in Helsinki or Maaninka, and there was no interaction between the N application rate and the year (Table 2). The N yield in Helsinki was 44% higher in 2019 than in 2020 (219 vs. 152 N kg ha$^{-1}$). Annual differences were observed also in Maaninka, where the N yield was 76% higher in 2020 than in 2019 (291 vs. 165 N kg ha$^{-1}$). As for the reference treatment plots in Helsinki, the N yield averaged 136 N kg ha$^{-1}$ in 2019 and 84 N kg ha$^{-1}$ in 2020.

The $N_{RE}$ of forage maize did not respond to the N application rate ($p = 0.242$) or the year ($p = 0.528$). There was no interaction between the N application rate and the year ($p = 0.484$). Hence, the $N_{RE}$ of all N application rates and both years were averaged, being 45%.

### 3.4. Plant Traits

In Helsinki, ears of forage maize reached developmental stage R5 (dent) both in 2019 and 2020 (data not shown). In Maaninka, ears reached the R2 stage (blister) in 2019, but in 2020, ears developed to the R3 stage (milk). However, ear development did not respond to the N application rate in either location, and the interaction between the N application rate and the year was not significant.

Plant height did not respond to the N application rate in Helsinki or Maaninka (Table 4). Nevertheless, plant height differed annually in both locations. In Helsinki, plants were 25% taller in 2020 than in 2019 (347 vs. 277 cm). In Maaninka, plants were 17% taller in 2020 than in 2019 (320 vs. 272 cm).

**Table 4.** Plant height, single plant dry mass, ear proportion of dry matter (DM) yield and DM content of ears and vegetative plant mass (stalk and leaves) in the field experiment conducted in Helsinki and Maaninka, Finland, in 2019 and 2020. Data shown are means. Standard error of means is given in parentheses ($n = 3$–4).

| Location | Year | N Application Rate | Plant Height (cm) | Single Plant Dry Mass (g) | Ear Proportion of DM Yield (%) | DM Content (g kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Ears | Vegetative Plant Mass |
| Helsinki | 2019 | 100N | 280 (8.4) | 221 (11.9) | 58 (0.9) | 458 (7.3) ab | 255 (3.4) |
| | | 150N | 274 (7.2) | 196 (10.1) | 58 (0.8) | 444 (6.2) a | 246 (3.1) |
| | | 200N | 277 (8.4) | 218 (11.9) | 58 (0.9) | 478 (7.3) b | 242 (3.4) |
| | 2020 | 100N | 343 (7.2) | 317 (10.1) | 51 (0.8) | 481 (6.2) | 197 (3.1) |
| | | 150N | 343 (7.2) | 352 (10.1) | 51 (0.8) | 475 (6.2) | 199 (3.1) |
| | | 200N | 354 (7.2) | 329 (10.1) | 51 (0.8) | 478 (6.2) | 203 (3.1) |
| | | *p*-value | | | | | |
| | | N | 0.603 | 0.868 | 0.951 | 0.026 | 0.229 |
| | | Y | <0.001 | <0.001 | <0.001 | 0.026 | <0.001 |
| | | N × Y | 0.647 | 0.034 | 0.720 | 0.051 | 0.009 |
| Maaninka | 2019 | 150N | 259 (13.1) | 216 (16.7) | 30 (2.0) | 241 (11.3) | 223 (3.3) |
| | | 200N | 287 (13.1) | 210 (16.7) | 29 (1.7) | 233 (11.3) | 220 (3.6) |
| | 2020 | 150N | 325 (13.1) | 272 (16.7) | 34 (1.7) | 323 (13.0) | 171 (3.6) |
| | | 200N | 315 (13.1) | 319 (16.7) | 39 (1.7) | 324 (11.3) | 179 (3.3) |
| | | *p*-value | | | | | |
| | | N | 0.264 | 0.270 | 0.268 | 0.785 | 0.312 |
| | | Y | 0.034 | 0.003 | 0.013 | <0.001 | <0.001 |
| | | N × Y | 0.044 | 0.167 | 0.132 | 0.698 | 0.058 |

DM = dry matter; N = nitrogen application rate (N kg ha$^{-1}$), Y = year, N × Y = interaction between the nitrogen application rate and the year. Means marked with different letters (a, b) differ significantly ($p < 0.05$) from each other within a year in Helsinki.

Single plant dry mass was not affected by the N application rate in Helsinki or Maaninka, although the interaction between the N application rate and the year was observed in Helsinki (Table 4). However, the pairwise comparison did not show significant differences between 100N, 150N and 200N. Annual differences in the single plant dry mass were observed in both locations, since plants were 57% and 39% heavier in 2020 than in 2019 in Helsinki and Maaninka, respectively.

The ear proportion of DM yield was not affected by the N application rate in Helsinki or Maaninka in either year (Table 4). In Helsinki, the ear proportion was higher in 2019 than in 2020 (58 vs. 51%). However, in Maaninka, the ear proportion was higher in 2020 than in 2019 (37 vs. 30%).

Ear DM content responded to the N application rate and the year in Helsinki (Table 4). In addition, an interaction between the N application rate and the year was observed. In 2019, 150N had a lower DM content compared with 200N, but in 2020, the ear DM content was not affected by the N application rate. Altogether, the ear DM content in Helsinki was slightly higher in 2020 than in 2019 (478 vs. 460 g $kg^{-1}$). In Maaninka, the N application rate did not affect the ear DM content. Nevertheless, the ears included 37% more DM in 2020 than in 2019 (324 vs. 237 g $kg^{-1}$).

The N application rate did not affect the DM content of the vegetative plant mass in Helsinki or Maaninka (Table 4). An interaction between the N application rate and the year was observed in Helsinki. However, the pairwise comparison did not show significant differences between 100N, 150N and 200N. Annual differences were observed at both locations, since the DM content of the vegetative plant mass was 24% and 27% higher in 2019 than in 2020 in Helsinki and Maaninka, respectively.

## 4. Discussion

The N application rate did not affect forage maize DM yield, similar to earlier observations by Kara and Pulli [12] in Finland, Greef et al. [40] in Germany and Lynch et al. [21] in Ireland. The lack of yield response can be related to the mean temperature of the growing season at the study sites, 13–15 °C, which is at the lower limit of the temperature requirement for maize [5] and markedly lower than the optimum temperature of 28–34 °C for maize [6,7]. In warmer areas, such as in Turkey, where the mean temperature of the growing season is 22 °C [41], and in New York (USA), where the mean temperature of the growing season is 19 °C [25], an increasing N application rate resulted in a higher DM yield. Therefore, maize does not necessarily respond to an increasing N application rate if the mean temperature of the growing season is 15 °C or below, as stated previously by Lynch et al. [21].

Moreover, soil organic matter (SOM) content influences the response of forage maize yield to the N application rate [21]. The SOM content was high (on average 9.5%) in Helsinki and moderate (on average, 4.1%) in Maaninka. The high SOM content in Helsinki was likely related partly to the long-term manure application on the experimental site, as suggested by Edmeades [42] and Tuulos et al. [43]. Combined with ploughing before sowing, the high SOM content can lead to a relatively high amount of mineralized N [43] which may fulfil a considerable share of the N requirement of maize under climatic conditions that are marginal for maize growth [21]. The roles of the SOM content and N mineralization were observed in the relatively high N yield of the reference treatment plots, approximately 110 N kg $ha^{-1}$. Thus, it is possible that N taken up by maize originated mostly from the soil instead of fertilisers during the experiment and, therefore, a maize yield response to N application was not observed.

Forage quality had a low or non-existent response to N application rates similarly to observations by Masoero et al. [26] in Italy, Sheaffer et al. [27] in Minnesota (USA) and Lynch et al. [21] in Ireland. However, the CP content responded to the N application rate, increasing from 100N to 200N. The CP content grew, since increasing the N application rate leads to a higher N accumulation in ears and vegetative plant mass [26]. The observations on forage quality responses are supported by Sheaffer et al. [27], according to whom the effect of the N application rate on the quality of forage maize yield has been generally unclear apart from the CP content. Hence, N application rates above 100 N kg $ha^{-1}$ and especially above 150 N kg $ha^{-1}$ are not required to enhance the quality and or yield of forage maize in Finland. The observation is consistent with the current maximum N application rate for forage maize according to the agri-environmental scheme, 100–140 N kg $ha^{-1}$, in Finland [44].

The observed $N_{RE}$ was 45%, which is within the global range of the $N_{RE}$ of forage maize, 35–50% [19]. Nevertheless, $N_{RE}$ did not respond to the increasing N application rate. The lack of $N_{RE}$ response may be related to the high variance in $N_{RE}$ results and the cool mean temperature of the growing season. In warmer conditions, such as in Indiana

(USA) [45] and Colorado (USA) [46], where the mean temperature of the growing season is between 19 and 23 °C, $N_{RE}$ has decreased with the increasing N application rate.

Generally, $N_{RE}$ below 50%, as observed in this study, is regarded as low according to Fageria and Baligar [22] and Sharma and Bali [23]. As $N_{RE}$ is generally an agronomic variable that indicates N use efficiency (NUE) [47], the results of the current study show that the NUE of forage maize may be considered low in the boreal region. Low NUE often results from excessive N fertilisation and a lack of synchrony between maize, N supply and demand [19,23]. Usually, all N is applied to maize before or at sowing, although the growth of maize is rather slow at the early seedling stage [48] and the N uptake of maize increases rapidly only in the middle of the vegetative period reaching its peak at silking [49]. Early N application combined with late N uptake of maize may lead to N losses. Excessive N is lost from the fields due to denitrification, volatilisation, leaching and run-off, and the N loss poses a risk to the environment and climate [19,23,50]. Therefore, N should be supplied at the time of the highest N demand, for instance, by using split N fertilisation, as recommended by Sharma and Bali [23]. Split N fertilisation may increase the yield [51,52] and the $N_{RE}$ of maize [45,52], although the yield response has not always been observed [25,45]. Results from Kara and Pulli [12] indicated that split fertilisation in Finland is unnecessary. However, modern cultivars have a generally higher N accumulation [16,45], and therefore split N fertilisation of forage maize could be studied with recent cultivars in the boreal region.

Generally, the DM yield observed was similar to or slightly higher than observed in Sweden during the 2010s [8,15]. Moreover, the DM yield was approximately 3–4 times higher than observed in Finland in the 1970s and 1980s [1,12,13]. An increase in DM yield is related to the rise in mean temperature of the growing season [53] and the development of modern, early maturing maize cultivars [4]. The early maturation of forage maize increases the ear proportion yield [21]. As an example, the ear proportion of the yield observed by Pulli et al. [1] was below 18% in most years, while in this study, the ear proportion of DM yield exceeded 50% in Helsinki and 30% in Maaninka. The grown ear proportion of yield resulted in a higher, even two-fold DM content of yield compared with observations by Pulli et al. [1,13], which explains the high DM yields observed in this study.

The DM yield, as well as the ear developmental stage at harvest, was stable between years in Helsinki because the temperature sum was similar in 2019 (867 °Cd) and 2020 (862 °Cd). In Maaninka, a lower temperature sum in 2019 (674 °Cd) led to a markedly lower DM yield compared to 2020 (712 °Cd). The temperature sum affected the DM yield via ear development since, in 2019, ears were only at the R2 stage and in 2020, ears reached the R3 stage. Moreover, the low precipitation in July and August 2019 limited the growth of maize and thus the DM yield in Maaninka. Water deficit limits growth since it reduces photosynthesis and the DM production of maize [54].

In Helsinki, forage starch content exceeded 200 g $kg^{-1}$ DM in 2019 but remained below 200 g $kg^{-1}$ DM in 2020. Surprisingly, the starch contents were lower compared with the starch contents observed at the R4–R5 stage in Sweden, 295–376 g $kg^{-1}$ DM [8]. The difference may be related to differences in weather conditions of the growing seasons as well as cultivar traits. The starch content in Maaninka was generally low, remaining below 130 g $kg^{-1}$ DM, although the starch content was rather close to the results obtained previously in Sweden at the R2–R3 stages, 40–50 g $kg^{-1}$ DM [4]. An annual variance in the starch contents was observed, and the differences between years were more substantial in Maaninka than in Helsinki, because the ear development stages that were reached differed annually in Maaninka. In addition to the ear development stages, ear DM content also affected the starch content since an increasing ear DM content indicates that carbohydrates (including sugars) are remobilised from vegetative plant parts to ears and converted there to starch [2,21,55]. The remobilisation of carbohydrates may be seen also in the sugar contents observed. As the starch content was markedly low in Maaninka, the sugar content was respectively high, ranging between 158 and 200 g $kg^{-1}$ DM. The high sugar content in Maaninka indicated that sugars were not yet converted extensively to starch. In Helsinki, a considerable share of sugars had already been used in starch synthesis, as the sugar content was below 100 g $kg^{-1}$ DM and the starch content was considerably higher than in Maaninka.

The forage CP content in Helsinki was similar in 2019 but lower in 2020 compared with previous studies that have observed CP content ranging from 66 to 93 g $kg^{-1}$ DM in Sweden [8,15]. The relatively low CP content in 2020 is related to the low ear proportion of yield in 2020, as ears have, in general, a higher CP content than vegetative plant parts [13,21,56]. Moreover, ear development influenced the results, since although the R stage was the same in both years, ears included more DM in 2020 than in 2019. The CP content of the yield tends to decrease with ear development [56,57] since, during ear filling, the plant breaks down CP to provide N for carbon assimilation [56]. In Maaninka, the CP content was close to that observed in Helsinki in 2019 and was within the range of the previous Swedish studies [8,15]. However, the CP content did not vary annually, although the ears had one further developmental stage in 2020 compared with 2019. Therefore, the decline of CP content, due to ear development, may not have yet started in Maaninka in 2019 or 2020.

In Maaninka, forage NDF content was markedly higher in 2019 than in 2020. Generally, the NDF content decreases as the ears develop and the ear proportion of yield increases [4,58] since ears include less NDF compared with leaves and stems [21,56]. Therefore, the annual difference in the NDF content is explained by the further ear development stage (R3) and the markedly higher ear proportion of yield in 2020 compared with 2019. The relatively high NDF content also explains the observed low D-values and, hence, lower in vitro digestibility in Maaninka in 2019 compared with 2020.

Overall, there were considerable annual differences in forage maize yield in Maaninka and forage quality in both Helsinki and Maaninka. Therefore, the fluctuation of forage maize yield and quality may remain a problem in the boreal region, as Farrell and Gilliland [59] have stated previously.

## 5. Conclusions

Production of relatively high forage maize yield was possible in the boreal region, even though the temperature sum limited ear development markedly at latitude 63° N. In addition, fluctuating temperatures and precipitation caused annual differences in the yield and the forage quality. Nitrogen application rates of 100–200N did not affect the response yield, quality or $N_{RE}$ of forage maize. Based on this investigation, the appropriate N application rate is more likely 100N than 150N for moderate to high SOM soils in the boreal region. To increase the low $N_{RE}$ observed in the study, the use of split N fertilisation could be studied in the future.

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## References

1. Pulli, S.; Tigerstedt, P.M.A.; Kara, O. Adaptation of silage maize varieties under extreme northern growing conditions in Finland. *Agric. Food Sci.* **1979**, *51*, 197–209. [CrossRef]
2. Struik, P.C. Physiology of Forage Maize (*Zea mays* L.) in Relation to its Production and Quality. Ph.D. Thesis, Landbouwhogeschool Wageningen, Wageningen, The Netherlands, 1983.
3. Allen, M.S.; Coors, J.G.; Roth, G.W. Corn silage. *Silage Sci. Technol.* **2003**, *42*, 547–608. [CrossRef]
4. Mussadiq, Z. Performance of Forage Maize at High Latitudes. Ph.D. Thesis, Swedish University of Agricultural Sciences, Umeå, Sweden, 2012.
5. FAO Crop Information: Maize. Available online: http://www.fao.org/land-water/databases-and-software/crop-information/maize/en/ (accessed on 18 March 2022).
6. Warrington, I.J.; Kanemasu, E.T. Corn growth response to temperature and photoperiod. I. Seedling emergence, tassel initiation, and anthesis. *Agron. J.* **1983**, *75*, 749–754. [CrossRef]
7. Birch, C.J.; Hammer, G.L.; Rickert, K.G. Temperature and photoperiod sensitivity of development in five cultivars of maize (*Zea mays* L.) from emergence to tassel initiation. *Field Crops Res.* **1997**, *55*, 93–107. [CrossRef]
8. Hetta, M.; Mussadiq, Z.; Gustavsson, A.M.; Swensson, C. Effects of hybrid and maturity on performance and nutritive characteristics of forage maize at high latitudes, estimated using the gas production technique. *Anim. Feed Sci. Technol.* **2012**, *171*, 20–30. [CrossRef]
9. Eckersten, H.; Herrmann, A.; Kornher, A.; Halling, M.; Sindhøj, E.; Lewan, E. Predicting silage maize yield and quality in Sweden as influenced by climate change and variability. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2012**, *62*, 151–165. [CrossRef]
10. Elsgaard, L.; Børgesen, C.D.; Olesen, J.E.; Siebert, S.; Ewert, F.; Peltonen-Sainio, P.; Rötter, R.P.; Skjelvåg, A.O. Shifts in comparative advantages for maize, oat and wheat cropping under climate change in Europe. *Food Addit. Contam. Part A* **2012**, *29*, 1514–1526. [CrossRef]
11. Peltonen-Sainio, P.; Jauhiainen, L.; Laurila, I.P. Cereal yield trends in northern european conditions: Changes in yield potential and its realisation. *Field Crops Res.* **2009**, *110*, 85–90. [CrossRef]
12. Kara, O.; Pulli, S. Rehumaissin typpilannoituksesta ja sadetuksesta. *Agric. Food Sci.* **1981**, *53*, 64–74. (In Finnish) [CrossRef]
13. Pulli, S.; Kara, O.; Tigerstedt, P.M.A. Management techniques of maize crop in the marginal growing area in Finland. *Agric. Food Sci.* **1979**, *51*, 210–221. [CrossRef]
14. Krizsan, S.J.; Mussadiq, Z.; Hetta, M.; Ramin, M.; Nyholm, L.; Huhtanen, P. Predicting feeding value of forage maize hybrids harvested at different maturities and sites. *J. Anim. Feed Sci.* **2014**, *23*, 269–278. [CrossRef]
15. Mussadiq, Z.; Hetta, M.; Swensson, C.; Gustavsson, A.M. Plant development, agronomic performance and nutritive value of forage maize depending on hybrid and marginal site conditions at high latitudes. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2012**, *62*, 420–430. [CrossRef]
16. Mueller, S.M.; Vyn, T.J. Maize plant resilience to N stress and post-silking N capacity changes over time: A review. *Front. Plant Sci.* **2016**, *7*, 53. [CrossRef] [PubMed]
17. Woli, K.P.; Sawyer, J.E.; Boyer, M.J.; Abendroth, L.J.; Elmore, R.W. Corn era hybrid dry matter and macronutrient accumulation across development stages. *Agron. J.* **2017**, *109*, 751–761. [CrossRef]
18. Hårdh, J.E. Sokerimaissin viljelystä sekä sitä haittaavista tekijöistä. *Agric. Food Sci.* **1955**, *27*, 179–186. [CrossRef]
19. Asibi, A.E.; Chai, Q.; Coulter, J.A. Mechanisms of nitrogen use in maize. *Agronomy* **2019**, *9*, 775. [CrossRef]
20. Ladha, J.K.; Pathak, H.; Krupnik, T.J.; Six, J.; van Kessel, C. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Adv. Agron.* **2005**, *87*, 85–156. [CrossRef]
21. Lynch, J.P.; O'Kiely, P.; Doyle, E.M. Yield, nutritive value and ensilage characteristics of whole-crop maize, and of the separated cob and stover components-nitrogen, harvest date and cultivar effects. *J. Agric. Sci.* **2013**, *151*, 347–367. [CrossRef]
22. Fageria, N.K.; Baligar, V.C. Enhancing nitrogen use efficiency in crop plants. *Adv. Agron.* **2005**, *88*, 97–185. [CrossRef]
23. Sharma, A.; Bali, S.K. A review of methods to improve nitrogen use efficiency in agriculture. *Sustainability* **2017**, *10*, 51. [CrossRef]
24. Ning, P.; Peng, Y.; Fritschi, F.B. Carbohydrate dynamics in maize leaves and developing ears in response to nitrogen application. *Agronomy* **2018**, *8*, 302. [CrossRef]
25. Cox, W.J.; Kalonge, S.; Cherney, D.J.R.; Reid, W.S. Growth, yield, and quality of forage maize under different nitrogen management practices. *Agron. J.* **1993**, *85*, 341–347. [CrossRef]

26. Masoero, F.; Gallo, A.; Zanfi, C.; Giuberti, G.; Spanghero, M. Effect of nitrogen fertilization on chemical composition and rumen fermentation of different parts of plants of three corn hybrids. *Anim. Feed Sci. Technol.* **2011**, *164*, 207–216. [CrossRef]
27. Sheaffer, C.C.; Halgerson, J.L.; Jung, H.G. Hybrid and N fertilization affect corn silage yield and quality. *J. Agron. Crop Sci.* **2006**, *192*, 278–283. [CrossRef]
28. IUSS Working Group WRB. *World Reference Base for Soil Resources 2014: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, Update 2015*; Resources Reports No. 106; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2015.
29. Brown, C. (Ed.) *Agronomy Guide for Field Crops*; Ministry of Agriculture Food and Rural Affairs: Guelph, ON, Canada, 2017.
30. Ebeling, M.E. The Dumas method for nitrogen in feeds. *J. AOAC Int.* **1968**, *51*, 766–770. [CrossRef]
31. Hall, M.B. Determination of starch, including maltooligosaccharides, in animal feeds: Comparison of methods and a method recommended for AOAC collaborative study. *J. AOAC Int.* **2009**, *92*, 42–49. [CrossRef]
32. Van Soest, P.J.; Robertson, J.B.; Lewis, B.A. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* **1991**, *74*, 3583–3597. [CrossRef]
33. Somogyi, M. A new reagent for the determination of sugars. *J. Biol. Chem.* **1945**, *160*, 61–68. [CrossRef]
34. Friedel, K. Die Schätzung des Energetischen Futterwertes von Grobfutter mit Hilfe einer Cellulasemethode. *Wiss. Z. Univ. Rostock N Reihe* **1990**, *39*, 78–86. (In German)
35. Nousiainen, J.; Rinne, M.; Hellämäki, M.; Huhtanen, P. Prediction of the digestibility of the primary growth of grass silages harvested at different stages of maturity from chemical composition and pepsin-cellulase solubility. *Anim. Feed Sci. Technol.* **2003**, *103*, 97–111. [CrossRef]
36. MAFF. *Energy Allowances and Feeding Systems for Ruminants*; Technical Bulletin 33; Ministry of Agriculture, Fisheries and Food: London, UK, 1975.
37. Varvel, G.E.; Peterson, T.A. Nitrogen fertilizer recovery by corn in monoculture and rotation systems. *Agron. J.* **1990**, *82*, 935–938. [CrossRef]
38. Ilmatieteen Laitos (Finnish Meteorogical Institute): Kuukausitilastot. Available online: https://www.ilmatieteenlaitos.fi/kuukausitilastot (accessed on 18 March 2022). (In Finnish)
39. NDAWN Center Corn Growing Degree Days (GDD). Available online: https://ndawn.ndsu.nodak.edu/help-corn-growing-degree-days.html (accessed on 18 March 2022).
40. Greef, J.M.; Ott, H.; Wulfes, R.; Taube, F. Growth analysis of dry matter accumulation and N uptake of forage maize cultivars affected by N supply. *J. Agric. Sci.* **1999**, *132*, 31–43. [CrossRef]
41. Çarpici, E.B.; Çelik, N.; Bayram, G. Yield and quality of forage maize as influenced by plant density and nitrogen rate. *Turk. J. Field Crops* **2010**, *15*, 128–132. [CrossRef]
42. Edmeades, D.C. The long-term effects of manures and fertilisers on soil productivity and quality: A review. *Nutr. Cycl. Agroecosystems* **2003**, *66*, 165–180. [CrossRef]
43. Tuulos, A.; Yli-Halla, M.; Stoddard, F.; Mäkelä, P. Winter turnip rape as a soil N scavenging catch crop in a cool humid climate. *Agron. Sustain. Dev.* **2015**, *35*, 359–366. [CrossRef]
44. Ruokavirasto: Ympäristökorvauksen Sitoumusehdot 2021. Available online: https://www.ruokavirasto.fi/viljelijat/oppaat/sitoumus-ja-sopimusehdot/ymparistokorvauksen-sitoumusehdot/ymparistokorvauksen-sitoumusehdot-2021/ (accessed on 18 March 2022). (In Finnish)
45. Mueller, S.M.; Camberato, J.J.; Messina, C.; Shanahan, J.; Zhang, H.; Vyn, T.J. Late-split nitrogen applications increased maize plant nitrogen recovery but not yield under moderate to high nitrogen rates. *Agron. J.* **2017**, *109*, 2689–2699. [CrossRef]
46. Halvorson, A.D.; Schweissing, F.C.; Bartolo, M.E.; Reule, C.A. Corn response to nitrogen fertilization in a soil with high residual nitrogen. *Agron. J.* **2005**, *97*, 1222–1229. [CrossRef]
47. Balasubramanian, V.; Alves, B.; Aulakh, M.; Bekunda, M.; Cai, Z.; Drinkwater, L.; Mugendi, D.; van Kessel, C.; Oenema, O. Crop, environmental, and management factors affecting nitrogen use efficiency. In *Agriculture and the Nitrogen Cycle*; Scope Series 65; Mosier, E.R., Syers, J.K., Freney, J.R., Eds.; Scientific Committee of Problems of the Environment (SCOPE): Paris, France, 2004; pp. 19–34.
48. Olfs, H.-W. Organic fertilization in maize cropping systems: Measures to reduce N losses. *Agronomy* **2021**, *11*, 793. [CrossRef]
49. Hanway, J.J. Growth stages of corn. *Agron. J.* **1963**, *55*, 487–492. [CrossRef]
50. Raun, W.R.; Johnson, G.V. Improving nitrogen use efficiency for cereal production. *Agron. J.* **1999**, *91*, 357–363. [CrossRef]
51. Fernandez, J.A.; DeBruin, J.; Messina, C.D.; Ciampitti, I.A. Late-season nitrogen fertilization on maize yield: A meta-analysis. *Field Crops Res.* **2020**, *247*, 107586. [CrossRef]
52. Davies, B.; Coulter, J.A.; Pagliari, P.H. Timing and rate of nitrogen fertilization influence maize yield and nitrogen use efficiency. *PLoS ONE* **2020**, *15*, e0233674. [CrossRef] [PubMed]
53. Tietäväinen, H.; Tuomenvirta, H.; Venäläinen, A. Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data. *Int. J. Climatol.* **2010**, *30*, 2247–2256. [CrossRef]
54. Earl, H.J.; Davis, R.F. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. *Agron. J.* **2003**, *95*, 688–696. [CrossRef]
55. Johnson, L.; Harrison, J.H.; Hunt, C.; Shinners, K.; Doggett, C.G.; Sapienza, D. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. *J. Dairy Sci.* **1999**, *82*, 2813–2825. [CrossRef]

56. Wiersma, D.W.; Carter, P.R.; Albrecht, K.A.; Coors, J.G. Kernel milkline stage and corn forage yield, quality, and dry matter content. *J. Prod. Agric.* **1993**, *6*, 94–99. [CrossRef]
57. Mandić, V.; Bijelić, Z.; Krnjaja, V.; Đorđević, S.; Brankov, M.; Mićić, N.; Stanojković, A. Harvest time effect on quantitative and qualitative parameters of forage maize. *J. Anim. Plant Sci.* **2020**, *31*, 103–107. [CrossRef]
58. Bal, M.A.; Coors, J.G.; Shaver, R.D. Impact of the maturity of corn for use as silage in the diets of dairy cows on intake, digestion, and milk production. *J. Dairy Sci.* **1997**, *80*, 2497–2503. [CrossRef]
59. Farrell, A.D.; Gilliland, T.J. Yield and quality of forage maize grown under marginal climatic conditions in Northern Ireland. *Grass Forage Sci.* **2011**, *66*, 214–223. [CrossRef]