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# Variability of morphological features, bud burst and flowering of Norway spruce (*Picea abies* [L.] Karst.) in the seed orchard of the Bielsk Forest District

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**Abstract.** The main aim of this paper was to characterize Norway spruce clones in terms of bud burst, flowering and morphological features. Observation and measurements were carried out in the Norway spruce seed orchard of the Bielsk Forest District in the north-eastern part of Poland. The seed orchard was established in 1989 and consists of 428 grafts of over 37 trees from the Białowieża Primeval Forest. An assessment of bud burst, stem forking, stem form, crown width, branch thickness, vitality, flowering and fructification as well as diameter measurements was done in 2013 and 2014.The results showed variability of morphological features among different clones as well as within individual clones. Differences among clones in spring bud development, stem form and branch thickness were statistically significant. Additionally, a positive correlation between male and female flowering was observed. The research also confirmed an influence of the healthiness of the grafts on seed production with trees in a weakened state producing more seeds.

**Keywords:** Norway spruce, grafts, seed production, quantitative traits, phenology, fructification, heritability

## 1. Introduction

Norway spruce (*Picea abies* [L.] Karst.) belongs to the section *Eupicea*, genus *Picea* and family *Pinaceae* (Seneta, Dolatowski 2009). In Poland, it is an important economic species, next to Scots pine and for the most part, occurs as an admixture species; however, at 1000–1500 m altitude, it forms pure stands. Norway spruce shows wide variability and polymorphism as a result of its natural range – from northern Scandinavia and Siberia to southern Europe. Intraspecific variation of Norway spruce in Poland has been investigated based mainly on provenance studies, which distinguished 13 regions with differentiated hereditary features (Giertych 1977). The differences between Norway spruce provenances depend on environmental and genetic factors and are reflected in the forms of tree crown, branches, cones and the bark observed in a given provenance.

In Poland, Norway spruce grows to 50 m tall with diameter at breast height (DBH) to 200 cm. It is shade tolerant and grows well in cool, sunny sites with high air humidity (Pirc 2006). In Poland, it occurs primarily in the northeastern part of the country as well as in the south – in the highland and mountainous regions as the main forest-forming species, next to Scots pine and beech.

Norway spruce is vulnerable to climate change and associated weather anomalies. In the 1990s, it strongly responded to drought stress and as a result, Poland's spruce stands showed noticeably decreased health condition. Consequently, due to reduced resistance, many Norway spruce stands were damaged by bark beetles (especially *Ips typographus* L.).

On the edge of its range (Scandinavia), Norway spruce produces cones every 11–12 years, and under Poland's climatic conditions – every 3–5 years (Tomanek 1966; Chałupka 1975). Now, biotic and abiotic factors have detrimental effects on cone production, which results in imbalance of seed production. Since the 1980s, there have been observed irregular seed yields and, for example, in the northeastern part of the country, good cone and seed crops were observed only in the years 1980, 1981, 1992, 1993, 1998 (Kantorowicz 2000).

Unsystematic cone and seed yields of Norway spruce caused shortage of good quality seeds in Poland's forest nurseries, thus at the turn of the 1980s and 1990s, there were established Norway spruce seed orchards. The opening text

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on the establishment of forest tree orchards was embraced in the programme on the improvement of seed management and the implementation of forest genetics achievements in the State Forests in the years 1975–1998 (1975). Nonetheless, only at the end of the 1980s, there were prepared the objectives and tasks on forest tree selection for practical realisation in State Forests' management units (Kocięcki 1988). All the preceding programmes on forest tree selection and seed orchards are reflected in the programme on conservation of forest genetic resources and selective breeding of forest trees in Poland for the years 1991–2010 Burzyński *et al*. 1993), which was amended in 2000 (Burzyński *et al*. 2000) and extended with the programme on conservation of forest genetic resources and selective breeding of forest trees in Poland for the years 2011–2035 (Barzdajn *et al*. 2009).

The aim of the present study is to examine Norway spruce (*Picea abies* [L.] Karst.) phenology (bud burst and flowering) and morphological features as well as to investigate their relationships. The study was conducted in a seed orchard located in the Grabowiec Forest Division (management unit 282w), the Bielsk Forest District (northeastern Poland).

## 2. Materials and Methods

### Norway spruce seed orchard

According to Poland's system of natural-forest regionalisation, almost the entire area of the Bielsk Forest District is situated in the IV Mazowsze-Podlasie Region, and only the northern part of the District (the Pawły Forest Division in the Zabłudów municipality) belongs to the II Mazury–Podlasie region. A greater part of the Bielsk Forest District within the Mazowsze–Podlasie region is categorised as 5. District of the Podlasie lowland and the Siedlce highland, mesoregion 'c' of the Bielsk highland (Trampler *et al*. 1986). In this region, average air annual temperature is 6.8°C (from −35.4 to + 35.5°C), and average annual precipitation is 593 mm (Górniak 2000).

The observed seed orchard was established in the spring 1989, within the area of the Forest Division Grabowiec, in the management unit 282w (the Bielsk sub-division). The seed orchard is situated within fresh deciduous mixed forest site (Forest Management Plan (PUL) 2008), on soils derived from glacial tills, sands and gravel. The area of the whole forest nursery is fenced (2-metre high metal gauze). Norway spruce seed orchard comprises vegetative progeny of 37 parent trees originating from the Białowieża Primeval Forest. Information on parental trees was obtained from the Polish Seed Register (1996) and is presented in Table. 1.

The map of Norway spruce distribution within the seed orchard was developed by the Forest Research Institute, Poland. Norway spruce seed orchard area is 2.04 ha and comprises 544 planted grafts. It is divided into 3 quarters with different areas: quarter no. 1–187 grafts, no. 2–170 and no. 3–187. Norway spruce trees were planted at 6 × 6 m density. After light felling, there remained 428 grafts and 2 of these died in 2013 (Fig. 1).

### Measurement methods

Field observations on Norway spruce grafts were conducted from May to September in 2013 and April 2014. The following tree features were examined:

- DBH [cm] to the nearest 0.5 cm,
- spring bud burst stage according to the scale described by Krutzsch (1973):

0 – resting buds,

1 – buds slightly swollen, needles below buds bent backwards and outwards,

2 – buds swollen, green to grey green in colour, bud scales still closed,

3 – burst of bud scales, needle tips emerging,

4 – first elongation of needles to about double bud length,

5 – first spread of needles, buds have the appearance of a painter's brush,

6 – shoot elongation, basal needles not yet spread,

7 – shoot differentiation, basal needles spread,

8 – all needles spread, new buds developing, almost full elongation.

For each graft, there was determined the bud burst stage (the mean value of bud developmental stages). Next, the bud burst index in the subsequent observation term ($W_T$) (Sabor *et al*.1999) was calculated for each clone – as the arithmetic mean of developmental stage values of all the specimens, in accordance with the following equation:

$$W_T = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where:
$n$ – the number of specimens of a given provenance
$x_i$ – value of mean bud burst stage of $i$ specimen

The analysis of spring bud burst variability in Norway spruce clones was based on the average bud burst index ($W_P$), calculated in the observed vegetation season using the following equation:

$$W_P = \frac{1}{kn}\sum_{j=1}^{k}\sum_{i=1}^{n} x_i$$

where:
$k$ – the number of observation terms,
$n$ – the number of specimens of a given provenance,
$x_i$ – value of mean bud burst stage of $i$ specimen.

Norway spruce clones with $W_P$ value lower than the mean ($x$) of all the clones in the seed orchard were classified as late

**Table 1.** Characteristic of the Norway spruce (*Picea abies* [L.] Karst.) plus trees from the Białowieża Primeval Forest used in 1989 to establish the seed orchard in the compartment 282w of the Bielsk Forest District

| No. | Tree No. Acc. IBL | Year of acceptance | Forest District | Precinct | Forest Range | Com-partment | Age | Height [m] | Diameter [cm] | Index of the quality / thickness |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3130 | no data | | | | | | | | |
| 2 | 3396 | 1984 | Białowieża | Białowieża | Krzyże | 448Da | 120 | 38 | 63 | A⁺ B |
| 3 | 3397 | 1984 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 36 | 58 | A⁺ B |
| 4 | 3398 | 1984 | Białowieża | Białowieża | Krzyże | 449Cc | 120 | 38 | 58 | a B |
| 5 | 3399 | 1984 | Białowieża | Białowieża | Krzyże | 449Cc | 120 | 38 | 54 | a b |
| 6 | 3400 | 1984 | Białowieża | Białowieża | Krzyże | 449Cb | 120 | 38 | 60 | A B |
| 7 | 3401 | 1984 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 37 | 63 | A⁺ B |
| 8 | 3402 | 1984 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 38 | 53 | A b |
| 9 | 3403 | 1984 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 36 | 54 | A⁺ B |
| 10 | 3415 | 1985 | Hajnówka | Leśna | Judzianka | 461Cd | 90 | 34 | 54 | A b |
| 11 | 3416 | 1985 | Hajnówka | Hajnówka | Wilczy Jar | 419Dd | 130 | 37 | 52 | a b |
| 12 | 3417 | 1985 | Hajnówka | Hajnówka | Wilczy Jar | 419Dd | 130 | 37 | 68 | a b |
| 13 | 3419 | 1985 | Hajnówka | Starzyna | Słobódka | 663Ab | 130 | 36 | 74 | A B |
| 14 | 3420 | 1985 | Hajnówka | Starzyna | Słobódka | 663Cb | 130 | 35 | 58 | A b |
| 15 | 3421 | 1985 | Hajnówka | Starzyna | Słobódka | 695Af | 140 | 35 | 56 | A b |
| 16 | 3422 | 1985 | Hajnówka | Starzyna | Słobódka | 663Da | 130 | 35 | 56 | a b |
| 17 | 3423 | 1985 | Hajnówka | Starzyna | Topiło | 666Ad | 140 | 35 | 62 | A B |
| 18 | 3424 | 1985 | Hajnówka | Starzyna | Topiło | 663Cd | 160 | 34 | 84 | a B |
| 19 | 3425 | 1985 | Hajnówka | Starzyna | Topiło | 669Dd | 150 | 36 | 84 | a B |
| 20 | 3426 | 1985 | Hajnówka | Starzyna | Topiło | 669Dd | 150 | 36 | 67 | A b |
| 21 | 3429 | 1985 | Browsk | Browsk | Loniczyno | 52Ab | 110 | 30 | 64 | a b |
| 22 | 3430 | 1985 | Browsk | Narewka | Nowosady | 149Bc | 140 | 32 | 50 | a b |
| 23 | 3431 | 1985 | Browsk | Narewka | Nowosady | 149Bc | 140 | 31 | 49 | A b |
| 24 | 3432 | 1985 | Browsk | Narewka | Nowosady | 150Bd | 130 | 32 | 66 | A B |
| 25 | 3433 | 1985 | Browsk | Narewka | Nowosady | 150Bd | 130 | 32 | 53 | A b |
| 26 | 3434 | 1985 | Browsk | Narewka | Nowosady | 150Bd | 130 | 32 | 52 | A b |
| 27 | 3435 | 1985 | Browsk | Narewka | Nowosady | 149Da | 130 | 34 | 54 | A b |
| 28 | 3448 | 1985 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 35 | 44 | A b |
| 29 | 3449 | 1985 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 39 | 49 | A b |
| 30 | 3450 | 1985 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 40 | 67 | a B |
| 31 | 3451 | 1985 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 38 | 58 | a b |
| 32 | 3452 | 1985 | Białowieża | Białowieża | Krzyże | 449Ca | 120 | 36 | 60 | a B |
| 33 | 3453 | 1985 | Białowieża | Białowieża | Krzyże | 448Da | 120 | 36 | 53 | A b |
| 34 | 3454 | 1985 | Białowieża | Białowieża | Krzyże | 449Ab | 130 | 38 | 65 | a B |
| 35 | 3455 | 1985 | Białowieża | Białowieża | Batorówka | 447Ac | 120 | 36 | 78 | a B |
| 36 | 3456 | 1985 | Białowieża | Białowieża | Batorówka | 447Bf | 110 | 34 | 60 | A⁺ b |
| 37 | 3458 | no data | | | | | | | | |

$A^+$ – very good quality
A – good quality
a – better quality than average tree
B – good growth tree, with diameter and height greather over 10% than comparative tree
b – diameter and height similar to average tree

Norway spruce seed orchard

Białystok RD, Bielsk Forest District, Grabowiec forest range

Established in: 1989

Number of clone: 37

Current number of grafts: 428

Spacing: 6×6 m

N

1

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3402 | 3403 | 3415 | 3424 | 3420 | 3421 | 3403 | 3400 | 3424 | | **3431** |
| 2 | 3420 | 3400 | | 3397 | 3402 | 3423 | 3399 | 3415 | | 3433 | |
| 3 | 3421 | 3423 | 3419 | 3432 | 3398 | 3448 | 3401 | 3419 | **3430** | 3454 | |
| 4 | 3424 | 3399 | 3430 | 3429 | | 3450 | 3433 | 3396 | 3449 | 3456 | |
| 5 | 3403 | 3415 | 3422 | 3456 | 3435 | 3421 | 3416 | 3453 | 3455 | | 3429 |
| 6 | | 3420 | 3453 | 3454 | 3419 | 3130 | 3424 | 3434 | | 3432 | 3433 |
| 7 | 3397 | 3402 | 3396 | 3399 | 3423 | 3403 | 3400 | 3450 | 3451 | 3449 | 3454 |
| 8 | 3421 | 3424 | 3416 | 3430 | 3429 | 3448 | 3398 | 3417 | 3430 | 3453 | 3435 |
| 9 | 3415 | | 3398 | | 3433 | | 3402 | 3456 | 3452 | | 3431 |
| 10 | | 3403 | 3397 | | | 3419 | 3399 | 3426 | 3434 | 3455 | |
| 11 | 3399 | 3420 | 3130 | 3435 | 3432 | 3424 | 3397 | | 3449 | | 3433 |
| 12 | 3402 | 3421 | 3415 | 3416 | 3423 | 3422 | 3403 | 3451 | | 3435 | 3456 |
| 13 | 3400 | 3424 | 3417 | | 3456 | 3420 | 3434 | | 3430 | | 3429 |
| 14 | | 3397 | 3422 | 3396 | 3400 | 3425 | 3429 | 3452 | 3455 | 3458 | |
| 15 | 3420 | 3399 | 3419 | | 3426 | 3402 | 3399 | | 3450 | | 3432 |
| 16 | 3421 | 3402 | 3454 | | 3415 | 3449 | | 3130 | 3456 | 3431 | 3435 |
| 17 | 3424 | 3400 | 3423 | 3403 | 3401 | | 3421 | 3432 | 3448 | | 3453 |

60 m

10 m

2

| | I | II | III | IV | V | VI | VII | VIII | IX | X |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 3402 | 3403 | 3420 | 3400 | 3415 | 3402 | 3421 | 3423 | 3399 |
| 2 | | 3424 | 3421 | 3419 | 3397 | 3399 | 3403 | 3433 | 3419 | |
| 3 | | | | 3422 | | 3424 | | 3401 | 3456 | 3431 |
| 4 | | 3397 | 3398 | | 3435 | 3420 | 3435 | | | 3453 |
| 5 | | **3403** | 3424 | 3450 | 3433 | 3434 | 3430 | **3455** | **3433** | 3454 |
| 6 | | | 3416 | | 3449 | | 3396 | 3456 | 3429 | 3449 |
| 7 | 3400 | 3401 | | 3419 | 3397 | **3402** | | 3130 | | 3448 |
| 8 | | 3399 | 3426 | 3456 | | 3423 | 3425 | | 3430 | 3453 |
| 9 | | 3423 | 3435 | 3398 | 3424 | 3400 | 3401 | | 3433 | 3456 |
| 10 | 3424 | 3402 | 3422 | 3415 | 3431 | 3421 | 3458 | | | |
| 11 | 3421 | 3397 | | 3396 | 3429 | 3416 | 3453 | | | 3449 |
| 12 | 3399 | 3400 | 3434 | | 3450 | 3402 | 3433 | 3448 | 3454 | 3435 |
| 13 | 3423 | 3403 | | 3421 | 3435 | 3424 | 3399 | 3417 | 3432 | 3453 |
| 14 | | | 3130 | | 3423 | | 3401 | 3430 | | |
| 15 | | 3415 | 3424 | 3420 | 3415 | 3419 | 3453 | 3422 | **3448** | 3429 |
| 16 | 3400 | 3450 | 3398 | | 3448 | 3400 | 3451 | 3455 | 3456 | |
| 17 | 3399 | 3429 | 3454 | 3433 | | 3430 | 3429 | 3435 | 3454 | 3432 |

54 m

10 m

3

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3402 | 3403 | | 3400 | 3424 | 3423 | 3420 | **3421** | **3400** | 3424 | 3403 |
| 2 | 3424 | 3423 | 3399 | | | **3403** | **3415** | | 3402 | | 3429 |
| 3 | 3415 | 3420 | | 3453 | **3429** | | | 3419 | 3456 | 3454 | |
| 4 | 3421 | 3400 | 3434 | | 3450 | | 3397 | | 3430 | | 3432 |
| 5 | | 3402 | | 3417 | | 3435 | 3423 | 3422 | | 3449 | |
| 6 | 3423 | 3424 | 3419 | 3420 | 3455 | 3400 | 3403 | | 3416 | 3429 | 3431 |
| 7 | 3399 | 3415 | 3397 | 3449 | | 3396 | 3399 | 3434 | 3433 | 3456 | |
| 8 | 3400 | | 3452 | 3433 | 3425 | 3415 | 3420 | 3419 | 3130 | 3430 | 3448 |
| 9 | 3424 | 3401 | 3402 | 3448 | 3424 | 3398 | | 3450 | | 3429 | |
| 10 | 3403 | 3423 | 3458 | 3419 | 3422 | | 3451 | 3396 | 3426 | 3449 | 3433 |
| 11 | | 3397 | 3399 | 3453 | 3454 | 3431 | 3430 | 3432 | | 3455 | |
| 12 | 3402 | | 3417 | 3403 | 3456 | 3402 | 3415 | 3398 | 3416 | | 3435 |
| 13 | 3400 | 3424 | | 3130 | 3433 | 3452 | | 3434 | | 3430 | 3429 |
| 14 | 3423 | 3415 | 3420 | 3397 | 3419 | 3399 | 3401 | 3455 | 3417 | 3456 | 3454 |
| 15 | 3403 | 3399 | 3455 | 3430 | | 3448 | | 3450 | 3449 | 3433 | |
| 16 | 3421 | 3402 | 3398 | 3454 | 3449 | 3456 | 3396 | | 3422 | 3435 | 3453 |
| 17 | 3424 | 3451 | 3432 | 3429 | 3431 | 3435 | 3433 | 3432 | | 3431 | |

60 m

96 m

**Figure 1.** Distribution of the Norway spruce (*Picea abies* [L.] Karst.) clones in a seed orchard in compartment 282w of the Bielsk Forest District, on 15th September 2013

**3403** – graft with cones,

– fall out graft

bud burst clones. Early bud burst clones were those with $W_P$ value higher than mean values obtained for the following morphological features:

• tree trunk ramification – estimated in accordance with the following point scale:

1 – the leader at the top of the trunk,
2 – the leader on the side shoot,
3 – forked tree trunk (two leaders),
4 – tree trunk without the leader.

• tree trunk straightness – estimated in accordance with the following point scale:

1 – entirely straight tree trunk,
2 – tree trunk with one or two minor contortions,
3 – tree trunk with more than three minor contortions or else – at least one extensive contortion.

• tree crown broadness – assessed based on the comparison of tree crown width (w) with its length (l), in accordance with the following point scale:

1 – narrow crown (w/l < 3/5),
2 – regular crown (4/5 > w/l ≥ 3/5),
3 – broad crown (w/l > 4/5).

• branch thickness – evaluated at the middle of crown height (judged against other tree crowns), in accordance with the following point scale:

1 – thin branches,
2 – medium thickness branches,
3 – thick branches.

• tree health – estimated in accordance with the following point scale:

1 – graft in perfect health,
2 – weakened graft, with minor defoliation and needle discolouration,
3 – diseased graft, with considerable defoliation and needle discolouration.

• flowering (male pollen cones and female cones separately) – estimated in accordance with the following point scale:

0 – no male pollen or female cones,
1 – several male pollen or female cones,
2 – more than a dozen male pollen or female cones,
3 – abundance of male pollen or female cones.

• cone production:

0 – no cones,
1 – 1–10 cones,
2 – 11–20 cones,
3 – more than 20 cones.

**Analysis of empirical data**

The results of the measurements and observations were analysed with no mathematical transformations in accordance with the following experimental model:

$$\textit{feature value} = \mu + R_m + E_n$$

where:
$\mu$ – the overall mean for the experiment
$R_m$ – the effect of the clone *m,*
$E_n$ – the effect of tree *n* in clone *m*

Calculations of variance and its components were performed using R programming language for statistical computing. All the tests were performed at α = 0.05. The effect of the clone was treated as a random variable. It was assumed that the effect of the block (quarter) had no random variable character, and thus it was not included in the heritability model.

Clone and individual heritability was calculated based on the values of variance components, following the models presented below (Giertych, Mąka 1994):

$$h_C^2 = \sigma_C^2 / \left( \frac{\sigma_E^2}{n} + \sigma_C^2 \right) \qquad \text{clone heritability}$$

$$h_S^2 = 4\sigma_C^2 / \left( \sigma_E^2 + \sigma_C^2 \right) \qquad \text{individual heritability}$$

where:
$\sigma_C^2$ – clone variance component
$\sigma_E^2$ – error variance component
$n$ – the mean number of grafts in a given clone.

Knowledge on heritability of a given feature allows for evaluation of the genetic value of the progeny of a given parent tree (clone). This can be done through calculation of the so-called clone index value (*WR*), which is the sum of the values assigned to the features observed (summing up feature values requires same units assigned to the features). The basic index assumes that the index value for each specimen can be presented as:

$$WR = w_1 h_C 1^2 P_1 + w_2 h_C 2^2 P_2 + \ldots + w_n h_C n^2 P_n$$

where:
*w* – coefficients weighing economic importance of features,
*h* – heritability of each feature,
*P* – the sum of multiplication results obtained for measurable phenotype features

At the same time, the Pearson correlation coefficients between all the features analysed were computed (α = 0.05).

## 3. Results

**Phenology of spring development**

Norway spruce phenology (also important in determination of frost resistance) was evaluated based on bud burst timing characteristics. The evaluation was conducted 3 times in 2013 (8 May, 4 June and 4 July) and once in 2014 (30 April). During 2-year observation period, there were found bud burst differences between the clones, which was confirmed by the analysis of variance (Table 2). The most significant differences were

**Table 2.** Summary of heritability, coefficient of variance, variance features of the Norway spruce grafts

| Feature | Clone variance | Error variance | Indywidual heritability | Clone heritability | Coefficient of variance [%] | ANOVA (p) |
|---|---|---|---|---|---|---|
| Diameter | 1.8410 | 36.6470 | 0.191 | 0.366 | 28.41 | 0.0143* |
| Stem form | 0.0549 | 0.3497 | 0.543 | 0.644 | 41.82 | 0.0000000476*** |
| Crown width | 0.0046 | 0.4299 | 0.042 | 0.110 | 26.81 | 0.460000 |
| Branches thickness | 0.0189 | 0.3275 | 0.218 | 0.399 | 27.51 | 0.00733** |
| Forking | 0.0190 | 0.5180 | 0.142 | 0.297 | 54.05 | 0.070900 |
| Bud burst (May 08, 2013) | 0.0514 | 0.2165 | 0.768 | 0.732 | 52.58 | 0.000000000743*** |
| Bud burst (June 06, 2013) | 0.0560 | 0.6749 | 0.307 | 0.489 | 12.59 | 0.00193** |
| Bud burst (July 04, 2013) | 0.0091 | 0.1834 | 0.188 | 0.362 | 5.54 | 0.0438* |
| Bud burst (April 30, 2014) | 0.2286 | 0.6221 | 1.075 | 0.726 | 51.16 | 0.00000000293*** |

observed at the beginning of spring development when bud burst reached very high clone heritability values (Table 2). The results on bud burst observed in 2 subsequent observation years (8 May 2013 and 30 April 2014) showed Norway spruce clones with early and late start of spring development. The beginning of spring development of Norway spruce grafts was strongly correlated with the observation years (Table 3). Norway spruce clones no. 3417 and 3435c were categorised as early start clones and stable regarding this feature, whereas clones 3400 and 3448 were categorised as late start clones (Fig. 2).

Developmental differences observed in grafts of a given clone were noticeable in three observation terms. The biggest variability was observed in June 2013, when seven of nine bud developmental stages (Krutzsch 1973) were observed. Within one clone, there were observed dormant grafts as well as those finishing their spring development, for example, no. 3399, 3402, 3403. The grafts within clones no.: 3426, 3424, 3396, 3397, 3398, 3401, 3416, 3422, 3431, 3433, 3434, 3450, 3451, 3452, 3454, 3458 showed minor bud burst variability (Fig. 3).

Bud burst indexes ($W_P$) were determined based on the observations carried out in 2013. There were found 13 late start clones and 22 early start clones. Two clones (3422, 3424) were assigned to none of the above groups since their $W_P$ value was same as the mean for the whole population in the seed orchard (Table 4).

## Tree trunk ramification and straightness

The results showed that in the seed orchard observed, tree trunk quality feature such as tree trunk ramification was satisfactory (coefficient of variation 54.05%) (Table 2). Three hundred thirty one grafts (77.80%) showed proper development (tree trunks with the leader), and 4.90% of the population examined had tree trunks without the leader. The leader on the side shoot was observed in 16.20% of the trees examined and forked trunks were found in 1.20%. At a clone level, the average estimated values ranged from 1.00 to 2.00. Norway spruce clones no.: 3396, 3425, 3426, 3433, 3452, 3454, 3456, 3458 were classified as best in terms of appropriate shape (Table 4). Statistical analysis showed no significant differences in tree trunk ramification in the clones tested. Individual heritability was 0.142 and clone heritability – 0.297 (Table 2).

Evaluation of tree trunk straightness showed that 284 (66.70%) specimens had straight trunk, 107 (24.60%) trees – tree trunks with minor contortions and contorted trunks were observed in 37 (8.70%) Norway spruce trees. At a clone level, the average estimated values ranged from 1.00 to 2.30. Norway spruce clones no. 3452, 3454, 3448, 3450, 3396 were classified as best in terms of appropriate shape (Table 4). Analysis of variance confirmed variability of tree trunk straightness in the clones tested at high value obtained for clone heritability (Table 2).

## Crown broadness and branch thickness

Narrow tree crown was observed in 45 Norway spruces (10.60% of the population examined). Medium crowns were found in 141 grafts (33.00%). Norway spruces with broad crowns (242 specimens, 56.30%) dominated in the seed orchard examined. At a clone level, the mean crown broadness values ranged from 2.15 to 3.00 (Table 4). Statistical analysis showed no significant differences among the clones examined with regard to crown broadness (Table 2). Tree crown broadness was the feature most strongly correlated with tree branch thickness and DBH (0.598***, 0.776***, respectively) (Table 3).

**Table 3.** Phenotype correlation of tested features of Norway spruce grafts

| Characteristic | Stem form (2013) | Diameter (2013) | Bud burst (May 08, 2013) | Bud burst (June 06, 2013) | Bud burst (July 04, 2013) | Bud burst (April 30, 2014) | Crown width (2013) |
|---|---|---|---|---|---|---|---|
| Stem form (2013) | x | -0.349*** | 0.074 | 0.013 | 0.039 | 0.072 | -0.241*** |
| Diameter | -0.349*** | x | 0.027 | 0.124* | 0.007 | -0.03 | 0.776*** |
| Bud burst (May 08, 2013) | 0.074 | 0.027 | x | 0.400*** | 0.213*** | 0.630*** | 0.063 |
| Bud burst (June 06, 2013) | 0.013 | 0.124* | 0.400*** | x | 0.510*** | 0.298*** | 0.226*** |
| Bud burst (July 04, 2013) | 0.039 | 0.007 | 0.213*** | 0.510*** | x | 0.183** | 0.097* |
| Bud burst (April 30, 2014) | 0.072 | -0.03 | 0.630*** | 0.298*** | 0.183** | x | -0.041 |
| Crown width (2013) | -0.241*** | 0.776*** | 0.063 | 0.226*** | 0.097* | -0.041 | x |
| Brachnes thickness (2013) | -0.107 | 0.693*** | 0.069 | 0.222*** | 0.110* | -0.047 | 0.598*** |
| Forking (2013) | 0.095* | -0.023 | -0.038 | -0.042 | 0.024 | -0.022 | -0.024 |
| Male flowering (2013) | 0.113* | -0.190*** | -0.236*** | -0.324*** | -0.078 | -0.268*** | -0.238*** |
| Female flowering (2013) | 0.054 | -0.162*** | -0.230*** | -0.425*** | -0.196*** | -0.236*** | -0.216*** |
| Male flowering (2014) | -0.047 | 0.183** | -0.096 | -0.016 | 0.064 | -0.243*** | 0.082 |
| Female flowering (2014) | -0.02 | -0.195** | -0.295*** | -0.384*** | -0.184** | -0.226*** | -0.326*** |
| Vitality (2013 | 0.293*** | -0.481*** | -0.194*** | -0.367*** | -0.145** | -0.175** | -0.506*** |
| Fructification (2013) | 0.083 | -0.134** | -0.185*** | -0.329*** | -0.132** | -0.210*** | -0.152** |

Within the seed orchard observed, there dominated Norway spruce trees with medium branch thickness (64.30%). The grafts with thin or thick branches constituted 14.20% and 21.50%, respectively. At a clone level, the mean estimated values of branch thickness ranged from 1.33 to 2.67. The finest branches were observed in the clone no. 3458 and the thickest in clones no. 3421 and 3425 (Table 4). Statistical analysis showed significant differences among the clones examined with regard to branch thickness. At the same time, clone hereditability was 0.399, individual heritability was 0.218 and coefficient of variation was 27.51% (Table 2).

## Clone index value

The value of the clone index (*WR*) was determined based on the estimates of tree trunk straightness, crown broadness and branch thickness. The calculations were performed using the calculation sheet for the assessment and designation of felling within seed orchards and seed-producing crops. Following the requirements of the calculation sheet (inclusion of at least 10 clones), 21 clones were used in calculations.

The obtained results showed the highest index values for the clones 3419, 3429, 3415, and the lowest for 3424, 3421, 3453 (Table 4). The results represent genetic value of the clones and should be taken into account at planning light felling. Bearing in mind maintenance of the effective number of clones, the grafts with the lowest index values should be gradually removed from the seed orchard for the benefit of correctly shaped trees.

## Flowering and cone production

The evaluation of clone flowering was carried out on 16 May 2013 and 30 April 2014. Male pollen cones were observed on 6.10 and 47.12% grafts, depending on the observation year. Female cones were observed on 4.23% (2013) and 8.63% (2014) grafts (Table 5). In the 2-year observation period, there was observed significant correlation between the production of male and female flowers (Table 3). It was found that flowering Norway spruces produced both male and female gametes.

Cone production within the seed orchard was assessed on 10 September 2013, that is, when the cones were fully developed. The cones produced were small (to approx. 10 cm) and achived half the length of the average size of Norway spruce cones. The cones were observed on 12 trees (2.80% of all Norway spruce trees examined). Four hundred and fo-

| Branches thickness (2013) | Forking (2013) | Male flowering (2013) | Female flowering (2013) | Male flowering (2014) | Female flowering (2014) | Vitality (2013) | Fructification (2013) |
|---|---|---|---|---|---|---|---|
| -0.107* | 0.095* | 0.113* | 0.054 | -0.047 | -0.02 | 0.293*** | 0.083 |
| 0.693*** | -0.023 | -0.190*** | -0.162*** | 0.183** | -0.195** | -0.481*** | -0.134** |
| 0.069 | -0.038 | -0.236*** | -0.230*** | -0.096 | -0.295*** | -0.194*** | -0.185*** |
| 0.222*** | -0.042 | -0.324*** | -0.425*** | -0.016 | -0.384*** | -0.367*** | -0.329*** |
| 0.110* | 0.024 | -0.078 | -0.196*** | 0.064 | -0.184** | -0.145** | -0.132** |
| -0.047 | -0.022 | -0.268*** | -0.236*** | -0.243*** | -0.226*** | -0.175** | -0.210*** |
| 0.598*** | -0.024 | -0.238*** | -0.216*** | 0.082 | -0.326*** | -0.506*** | -0.152** |
| x | 0.045 | -0.159*** | -0.163*** | 0.239*** | -0.214*** | -0.424*** | -0.126** |
| 0.045 | x | 0.155** | 0.162*** | 0.109 | 0.218*** | 0.168*** | 0.159*** |
| -0.159*** | 0.155** | x | 0.718*** | 0.227*** | 0.442*** | 0.453*** | 0.641*** |
| -0.163*** | 0.162*** | 0.718*** | x | 0.173** | 0.480*** | 0.370*** | 0.863*** |
| 0.239*** | 0.109 | 0.227*** | 0.173** | x | 0.313*** | 0.045 | |
| -0.214*** | 0.218*** | 0.442*** | 0.480*** | 0.313*** | x | 0.395*** | |
| -0.424*** | 0.168*** | 0.453*** | 0.370*** | 0.045 | 0.395*** | x | 0.318*** |
| -0.126** | 0.159*** | 0.641*** | 0.863*** | 0.104 | 0.182** | 0.318*** | x |

urteen grafts (97.20%) produced no seeds in the analysed vegetation season. At a clone level, 11 trees produced cones, (cones were observed at one graft from clone).

**Tree health**

The evaluation of Norway spruce health was carried out on 24 May 2013. The health condition of spruce trees examined in the seed orchard was satisfactory. Three hundred and eighty one (89.40%) specimens showed neither disease symptoms nor needle discolouration. Discolouration of the needles (assimilation apparatus damage) and poor health status was observed in 13 trees (3.10%). At a clone level, health estimates ranged from 1.00 to 1.67. No more than perfectly healthy specimens were observed in the following clones: 3130, 3398, 3417, 3422, 3425, 3431, 3434, 3449, 3450, 3452, 3454 (Table 4).

Phenotype correlations showed that tree health was strongly associated with other features examined with the exception of male flowering in 2014 (Table 3). In 2013, Norway spruce health was strongly correlated with male and female flowering (0.453***; 0.370***, respectively). Correlation coefficients indicated that in the year of poor cone yield, weakened trees flowered more intensely when compared with perfectly healthy clones. Weakened grafts (evaluation based on correlation coefficients) had narrower crowns, less straight tree trunks and thinner branches as well as forked leaders.

## 4. Discussion

Norway spruce is one of the main forest forming tree species in Poland, especially in the northeastern and southern parts of the country. As an important tree species, yet vulnerable to climate change, it needs the protection as well as selection towards building population of specimens with the best quantitative and qualitative features.

In Poland's forests managed by the State Forests National Forest Holding, Norway spruce selection has been carried out in line with long-term breeding programmes, comprising recommendations on seed stands, managed seed stands, parent trees and procedures for forest basic material. Breeding material has been acquired from selected specimens or populations with the best phenotype features. Seed orchards were established to facilitate collection of adequate numbers of Norway spruce seeds with high genetic value. Undertaken selection activities have enhanced forest production and

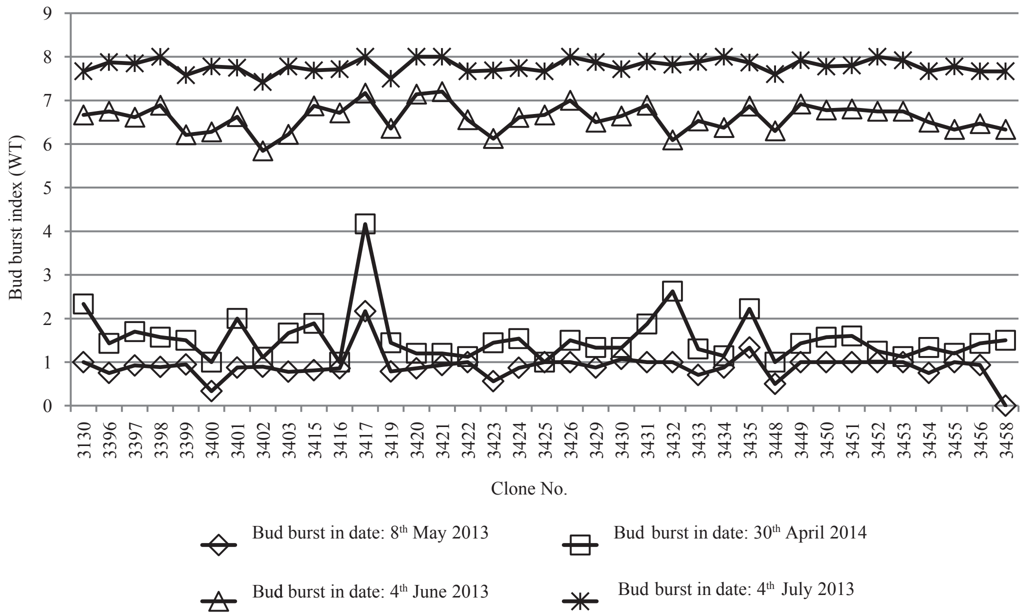


**Figure 2.** Coefficient of bud burst in the clones in different terms in 2013 and 2014

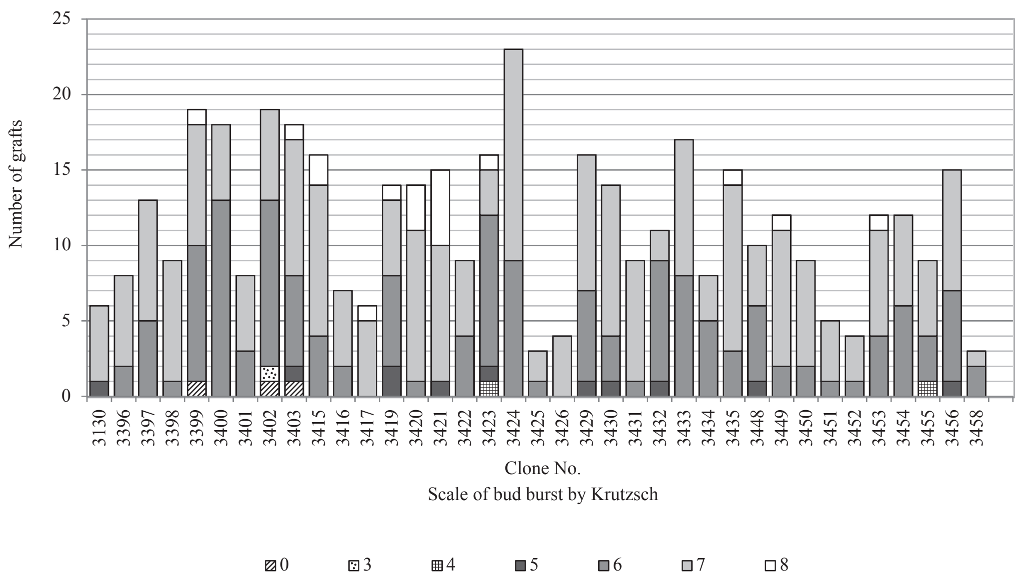


**Figure 3.** Variability of bud burst within the clones, on 4th June 2013

at the same time, the effects of various environmental factors have been decreased and those of genetic factors – increased. An important factor in successful seed orchard performance is site fertility, which improves cone and seed production (Tyszkiewicz 1949; Załęski 1995; Boratyński, Bugała 1998; Buraczyk 2009). Stimulation of tree flowering can be another factor with a positive influence on cone and seed production within seed orchards. In Poland, the methods of flowering stimulation were described by Chałupka (1985, 1987, 1991, 1997). On the other hand, however, the results then obtained were not definite enough to support fully reliable methodology for stimulation of Norway spruce flowering. Markiewicz (2006) conducted a study on stimulation of flowering of the European larch and found that ringing was more effective in the year of poor larch flowering. There also was observed that larch clones and half-sib families with naturally low flowering ability showed the uppermost growth.

In the present study, data collected during the vegetation seasons 2013 and 2014, provided information on Norway spruce variability, flowering and cone production in vegetative progeny of maternal trees planted in 1989 within the seed orchard established in the Bielsk Forest District. The analysis

**Table 4.** Summary of morphological features and breeding index of the Norway spruce (*Picea abies* (L.) Karst.) clones in a seed orchard in the Bielsk Forest District

| No. | Clone No. | Number of grafts | Diameter [cm] | Crown width | Stem straightness | Forking | Branch thickness | Bud burst Index ($W_p$) | ***WR*** Breeding Index |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3130 | 6 | 22.33 | 2.5 | 1.17 | 1.17 | 1.83 | 5.11 | |
| 2 | 3396 | 8 | 23.06 | 2.5 | 1.13 | 1 | 2.13 | 5.13 | |
| 3 | 3397 | 13 | 18.92 | 2.15 | 1.38 | 1.62 | 2 | 5.13 | 0.21 |
| 4 | 3398 | 9 | 26.11 | 3 | 1.33 | 1.22 | 2.33 | 5.26 | |
| 5 | 3399 | 19 | 20.68 | 2.53 | 1.32 | 1.42 | 1.95 | 4.91 | 0.45 |
| 6 | 3400 | 18 | 19.35 | 2.39 | 1.39 | 1.11 | 1.94 | 4.8 | 0.30 |
| 7 | 3401 | 8 | 22.5 | 2.25 | 1.25 | 1.38 | 2.38 | 5.08 | |
| 8 | 3402 | 19 | 21.39 | 2.37 | 1.21 | 1.37 | 2.16 | 4.72 | 0.31 |
| 9 | 3403 | 18 | 20.22 | 2.28 | 1.61 | 1.22 | 1.89 | 4.93 | -0.09 |
| 10 | 3415 | 16 | 17.27 | 2.38 | 1.38 | 1.56 | 1.81 | 5.13 | 0.56 |
| 11 | 3416 | 7 | 23.14 | 2.57 | 1.43 | 1.71 | 2 | 5.1 | |
| 12 | 3417 | 6 | 24.75 | 2.5 | 1.83 | 1.33 | 2.17 | 5.78 | |
| 13 | 3419 | 14 | 22.04 | 2.5 | 1.14 | 1.07 | 2 | 4.88 | 0.74 |
| 14 | 3420 | 14 | 22.71 | 2.5 | 1.29 | 1.5 | 2.07 | 5.33 | 0.30 |
| 15 | 3421 | 15 | 22.67 | 2.93 | 1.8 | 2 | 2.53 | 5.38 | -1.64 |
| 16 | 3422 | 9 | 24.94 | 2.56 | 1.33 | 1.11 | 2.22 | 5.07 | |
| 17 | 3423 | 16 | 20.84 | 2.44 | 1.69 | 1.5 | 2 | 4.79 | -0.45 |
| 18 | 3424 | 23 | 19.76 | 2.35 | 2.3 | 1.43 | 2.3 | 5.07 | -2.33 |
| 19 | 3425 | 3 | 26.67 | 2.67 | 1.33 | 1 | 2.67 | 5.11 | |
| 20 | 3426 | 4 | 19.63 | 2.5 | 1.25 | 1 | 2 | 5.33 | |
| 21 | 3429 | 16 | 20.3 | 2.25 | 1.25 | 1.25 | 1.88 | 5.08 | 0.72 |
| 22 | 3430 | 14 | 20.38 | 2.57 | 1.36 | 1.29 | 1.93 | 5.14 | 0.40 |
| 23 | 3431 | 9 | 18.44 | 2.44 | 1.67 | 1.22 | 2 | 5.26 | |
| 24 | 3432 | 11 | 18.14 | 2.36 | 1.55 | 1.55 | 1.73 | 4.97 | 0.34 |
| 25 | 3433 | 17 | 22.74 | 2.35 | 1.24 | 1 | 2.06 | 5.04 | 0.43 |
| 26 | 3434 | 8 | 21.56 | 2.38 | 1.25 | 1.13 | 2.25 | 5.08 | |
| 27 | 3435 | 15 | 21.1 | 2.27 | 1.27 | 1.47 | 2.2 | 5.36 | 0.12 |
| 28 | 3448 | 10 | 24.55 | 2.7 | 1.1 | 1.5 | 2.2 | 4.8 | 0.48 |
| 29 | 3449 | 12 | 24.04 | 2.75 | 1.17 | 1.33 | 2.5 | 5.28 | -0.19 |
| 30 | 3450 | 9 | 24.5 | 2.67 | 1.11 | 1.33 | 2.22 | 5.19 | |
| 31 | 3451 | 5 | 23.6 | 2.6 | 1.6 | 2 | 2.4 | 5.2 | |
| 32 | 3452 | 4 | 20.88 | 2.75 | 1 | 1 | 1.75 | 5.25 | |
| 33 | 3453 | 12 | 16.32 | 2.25 | 2 | 1.17 | 1.83 | 5.22 | -0.84 |
| 34 | 3454 | 12 | 23.21 | 2.58 | 1.08 | 1 | 2.25 | 4.97 | 0.43 |
| 35 | 3455 | 9 | 20.44 | 2.67 | 1.22 | 1.67 | 2 | 5.04 | |
| 36 | 3456 | 15 | 19.47 | 2.2 | 1.4 | 1 | 1.93 | 5.02 | 0.29 |
| 37 | 3458 | 3 | 14.67 | 2.33 | 1.67 | 1 | 1.33 | 4.67 | |
| Average | | | **21.2** | **2.46** | **1.42** | **1.33** | **2.08** | **5.07** | **0.01** |
| Standard deviation | | | **6.63** | **0.68** | **0.65** | **0.74** | **0.59** | **0.21** | **0.58** |

**Table 5.** Male and female flowering of Norway Spruce clones in a seed orchard in the Bielsk Forest District

| Flowering | | **2013** | **2014** |
|---|---|---|---|
| **A** | | | |
| Total number of clones | | 37 | 37 |
| Female flowering | | 14 | 16 |
| | % | 37.84% | 43.24% |
| Male flowering | | 20 | 36 |
| | % | 54.05% | 97.30% |
| **B** | | | |
| Total number of grafts | | 426 | 278 |
| Female flowering | | 18 | 24 |
| | % | 4.23% | 8.63% |
| Male flowering | | 26 | 131 |
| | % | 6.10% | 47.12% |

of Norway spruce morphological features indicated differences among the clones examined, and these were statistically significant (with the exception of tree crown broadness and tree trunk ramification). The results of analysis of variance obtained in this study are in reference to the results obtained by the Forest Research Institute, Poland, before light felling performed in the seed orchard observed. Then (in 2011), Norway spruce features analysed comprised Norway spruce tree trunk straightness, crown broadness and branch thickness. There were found significant differences among the clones examined with regard to the features checked except for crown broadness. In 2011, clone heritability of the features tested was 0.58 for tree trunk straightness, 0.21 for crown broadness and 0.47 for branch thickness. In the present study, analogous measurements carried out in 2013 showed the following heritability values: tree trunk straightness – 0.64, crown broadness – 0.11, branch thickness – 0.40. Variability of the examined clones was confirmed and indicated comparable values in subsequent observation years even though the measurements were conducted by different researchers.

At the same time, the study showed clone variability of bud development phenology. The grafts showed differentiated bud development stages. Grafts of an individual clone have the same genotype, nonetheless, they develop at different rates. The results of other studies on spring development of Norway spruce vegetative progeny (Szwajka 2011) validate the results of the present study.

The index $W_P$ distinguished the Norway spruce clones investigated into early and late development forms (13 and 22 clones, respectively). Two of the clones examined were not assigned to any of these types due to the fact that both of them showed $W_P$ value equal to the overall mean obtained for all the clones observed in the seed orchard. Early start of spring growth threatens the youngest Norway spruce trees since these are vulnerable to late frost, especially when grow in open areas (Jaworski 1995). Understanding clone variability of spring, bud burst requires further research in order to collect information needed for decision-making processes with regard to seed orchard management.

In northeastern Poland, Norway spruce cone yields were low in the observation years 2013 and 2014. Based on correlation coefficients between tree health and female flowering (0.370*** and 0.395*** for 2013 and 2014, respectively), the assumption was confirmed that in the year of crop failure, physiologically weakened trees started producing more seeds so as to pass their genes on to progeny (Tyszkiewicz 1949; Tomanek 1966; Boratyński, Bugała 1998).

In seed orchards, Norway spruce male and female flowerings are strongly correlated (Chałupka 1988). This was confirmed in the present study by correlation coefficients between the number of male pollen and female cones produced by the grafts in 2013 (0.718***). In 2014, correlation coefficient between male pollen and female cones was much lower – 0.313***, which was probably due to the term of observation (30 April) – when not all female cones were yet detectable.

The obtained results indicate high variability of Norway spruce grafts and clones as well as complexity of cone production processes. Consequently, there is a need for further research in this field. Studies on Norway spruce cone production are of particular importance in view of currently observed climatic changes and unpredictable weather conditions. Long-term observations on Norway spruce flowering and seed production within seed orchards indicate similar patterns of cone production as those observed in mature stands (Dietrichson 1989, Nikkanen, Ruotsalainen 2000). Evaluation of Norway spruce cone yields carried out in the Białowieża Primeval Forest showed distinct relationships between cone production and tree thickness (Buraczyk 2002). Another important aspect (confirmed by long-term studies) is a relationship between tree crown length and seed production. In natural stands, Norway spruce trees, which produce seeds abundantly, must uphold crowns longer than 60% of their height (Buraczyk 2005). The length of the crown is very much important for trees growing in seed orchards – by definition established for the production of seeds with high genetic value.

In summary, there should be emphasised that there occurs considerable variability among Norway spruce clones, which ought to be taken into consideration during light felling. The grafts of the clones with the worst features should be gradually removed for the benefit of superior specimens. Due to relatively small clone numbers grown within seed orchards, selective light felling resultant in the complete removal of the worst clones is not possible. Selective felling should be conducted within a specific time frame considering tree density, and this aspect is often neglected by seed orchard managers. Delayed treatments stop the progress of tree crown development and reduce seed production (Buraczyk 2006). Establishment of appropriate relationships between tree crown length and the number of produced seeds should constitute a basis for further elaboration of management principles and recommendations, especially within the areas that serve as seed production sites (Kantorowicz 2000).

## 5. Conclusions

1. Norway spruce clones growing in the Bielsk Forest District seed orchard are characteristic of high variability with regard to the features examined, which was statistically confirmed in the case of spring bud development phenology, tree trunk straightness and branch thickness.

2. In general, Norway spruce male and female flowerings are strongly positively correlated, which was validated by the study results obtained in the year 2013.

3. In the year of poor seed yield, physiologically weakened Norway spruce grafts produce more cones.

4. There were found differences in bud development rates between grafts of the same Norway spruce clone.

## Conflict of interest

The authors declare no conflict of interest.


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## Author's contribution

S.M. – conception, data collection, literature review, manuscript preparation;
M.R. – statistical analysis, manuscript revision.

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