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Research Article

Effect of seed size on soil cover, yield, yield components and nitrogen uptake of two-row malting barley

Einfluss von Saatkorngröße auf Bodenbedeckung, Ertrag, Ertragskomponenten und Stickstoffaufnahme von zweizeiliger Braugerste

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Summary

Seed size can influence germination, growth and yield formation of crops. A two-year field experiment was conducted in eastern Austria in 2012 and 2013 with two cultivars (Paula and Tatum) and four seeds size (< 2.5, 2.5–2.75, 2.75–3.25 and > 3.25 mm) to assess the effect of seed size on soil coverage, yield, yield components, nitrogen concentrations and nitrogen yield of spring malting barley. Soil coverage during the vegetation period was higher with a larger seed size in one year. Above-ground biomass and grain yield were not affected by seed size but differed between varieties and years. Seed size, however, affected the yield components. Both varieties had a higher ear density with the largest seed size compared to the smallest seed size. Higher ear density resulted in a lower thousand kernel weight. Grains ear-1 did not differ between seed sizes. Harvested grain fractions, nitrogen concentrations and nitrogen yields were also not affected by seed size.

Keywords: Malting barley, germination, soil coverage, yield components, nitrogen

Zusammenfassung

Die Saatkorngröße kann Keimung, Wachstum und Ertragsbildung von Nutzpflanzen beeinflussen. Ein zweijähriges Feldexperiment wurde in östlichen Österreich 2012 und 2013 mit zwei Gerstensorten (Paula und Tatum) und vier Korngrößen (< 2,5, 2,5–2,75, 2,75–3,25 und > 3,25 mm) durchgeführt, um den Einfluss der Saatkorngröße auf die Bodenbedeckung, den Ertrag, Ertragskomponenten und Stickstoffgehalte und -erträge von zweizeiliger Sommerbraugerste zu erheben. Die Bodenbedeckung war während der Vegetationsperiode in einem Jahr mit größeren Körnern höher. Die oberirdische Biomasse und der Kornertrag wurden durch die Korngröße nicht beeinflusst, jedoch gab es Unterschiede zwischen den Sorten und Jahren. Die Korngröße beeinflusst die Ertragskomponenten. Beide Sorten hatten die höchste Ährendichte bei der größten Saatkorngröße im Vergleich zur kleinsten. Die höhere Ährendichte führte aber zu einem kleineren Tausendkorngewicht. Die Anzahl an Körnern pro Ähre unterschied sich nicht zwischen den Korngrößen. Ebenso gab es keine Unterschiede bei den Korngrößenfraktionen im Erntegut, den Stickstoffgehalten und -erträgen zwischen den Saatkorngrößen.

Schlagworte: Braugerste, Keimung, Bodenbedeckung, Ertragskomponenten, Stickstoff

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1. Introduction

Several important factors around sowing affect germination, emergence, crop stand establishment, early vigor and consequently, yield formation in crop cultivation. Among those factors are soil cultivation and sowing method (conventional tillage, conservation tillage, no-till), seeding rates, sowing dates, row and inter-row spacing, plant population density, uniformity of the seed distribution, nutrient supply in the soil, soil reaction, waterlogging, allelopathy caused by decomposing crop residue (Varga et al., 2000; Agegnehu and Honermeier, 1997; Bavec et al., 2002; Kübler et al., 2002; Munir, 2002; Steffens et al., 2005; Tsybulya, 2002; Lošák et al., 2012 Chovancova et al., 2015; Neugschwandtner et al., 2015a; b) and sowing rates in intercropping designs (Neugschwandtner and Kaul, 2014; 2016).

Further, seed quality is important for emergence and compensation of stress affecting germination and the seedling (Heyland and Meer, 1992). Seed value is determined by inner and outer characteristics, among those are, for example, purity (of the seed lot), germination capacity, germination speed, seed vigor and the mean seed size (thousand kernel weight) (Klapp, 1967). Seed quality can be impaired by mechanical damage and stress cracks during drying and conditioning (Naplava et al., 1994; 1995) and enhanced through pre-treatment by either pre-soaking or application of plant growth regulators or nutrients; thereby cold tolerance, emergence, development and yield can be enhanced (Aufhammer and Federolf, 1992a, b; Heyland and Meer, 1992; Bavec et al., 2002). Diverse results for the effect of seed size have been reported. A higher germination rate, seedling and root length and higher yield have been reported for spring oat with a larger seed size (Guberac et al., 1998) and an increase in yield and yield components for spring barley (Rukavina et al., 2002). Contrastingly, Gan and Stobbe (1995) reported that seed size did not affect spring wheat emergence and yield, whereas sowing depth did.

The aims of this study were to compare the effects of seed size on: (i) soil coverage, (ii) yield and yield components and (iii) nitrogen (N) concentrations, N yield and N utilization for two malting barley varieties under Pannonian climate conditions in eastern Austria to gain knowledge whether the sowing of optimized seed size might be a promising cultivation technique.

2. Material and Methods

2.1 Experimental treatments

Four seed sizes of the two spring malting barley genotypes Paula and Tatum were tested in a germination and a two-year field experiment. Both varieties are commercial varieties from the breeding company Probstdorfer Saatzucht listed in the Austrian Descriptive Variety List. Both varieties were registered in 2010. The four seed sizes < 2.5 mm, 2.5–2.75 mm, 2.75–3.25 mm and > 3.25 mm were obtained by sieving commercial seeds. The thousand kernel weight (TKW) of the seed sizes was as follows (from low to high seed size): Paula – 34.0, 39.4, 50.5 and 54.7 g, Tatum – 35.4, 43.0, 53.9 and 59.8 g.

2.2 Germination experiment

A germination assessment was conducted according to the pleated paper method (ISTA, 2008) using Grade 3014 Seed Testing Paper (Wenk LabTec GmbH, Germany). One-hundred seeds were placed in boxes with four seeds in each of the 25 pleats. A paper strip underlying the pleated paper was used to ensure uniform moisture conditions. Germination progress was measured at 24 h intervals for 7 days. Seed were regarded as germinated after a radical emergence of 2 mm. The following germination indices were calculated: total germination (Chiapusio et al., 1997) and mean germination time (Ranal et al., 2009).

2.3 Field experiment

2.3.1 Experimental site and weather conditions

The experiment was carried out in Raasdorf (48° 14' N, 16° 33' E) on the experimental farm Groß-Enzersdorf of the University of Natural Resources and Life Sciences Vienna (BOKU). Raasdorf is located to the east of Vienna, Austria, on the edge of the Marchfeld plain, an important crop production region in the north-western part of the Pannonian Basin. The soil is classified as a chernozem of alluvial origin and is rich in calcareous sediments (pH_{CaCl2} = 7.6). The texture is silty loam; soil organic carbon content is at 2.2–2.3%. At sowing in 2012 and 2013, soil mineral nitrate (NO_3-N) was at 11.3 and 8.2 g m^{-2} (0–90 cm). The long-term mean annual temperature was 10.7°C and mean annual precipitation was 543 mm (1983–2012). Table 1

Table 1. Long-term average monthly temperature and precipitation (1983–2012) and deviations during the 2012 and 2013 growing seasons
Tabelle 1. Langjährige monatliche Durchschnittstemperaturen und - niederschläge (1983-2012) und die Abweichungen in den Vegetationsperioden 2012 und 2013

	Temperature (°C)			Precipitation (mm)		
	Mean (1983-2012)	2012 (±)	2013 (±)	Mean (1983-2012)	2012 (±)	2013 (±)
March	5.9	2.8	-2.4	37.8	-21.8	-11.8
April	11.1	0.3	0.8	36.6	-10.4	-25.7
May	15.8	1.4	0.0	57.9	-31.1	29.6
June	18.7	2.2	0.1	72.7	-26.2	30.9
July	21.1	1.3	1.4	64.6	75.3	-52.9

shows long-term average monthly temperatures and precipitation during spring barley growth from February to July and deviations during two experimental seasons. The temperature was considerably higher in 2012 compared to 2013 (except for April) and the long-term average. In the middle of March 2013, snowfall caused a snow cover for about three weeks, which delayed the emergence of the sown seeds considerably. The vegetation period 2012 was much dryer compared to 2013 and the long-term average. In 2013, there was less precipitation in March, April and July, but more precipitation in May and June compared to the long-term average.

2.3.2 Experimental treatments and measurements

Seedbed preparation was done with a tine cultivator to a depth of 20 cm. Sowing was performed on the 12th of March in both years 2012 and 2013, with a sowing rate of 300 seeds m^{-2} and a sowing depth of 3 cm (row distance: 13 cm; plot size: 15 m^2). No fertilization was applied. Weeds were controlled mechanically.

Percentage of soil cover of the crops was measured during the growing period by an image analysis of digital color pictures according to Richardson et al. (2001) and Karcher and Richardson (2005) using SigmaScan Pro5 software. Digital photos were taken of every plot from a constant height of 1 m above the ground.

Plants were harvested manually at full ripeness; sampling was performed on 1.2 m² per plot on 3rd of July 2012 and 23rd of July 2013. Plant length was measured on 20 plants per plot after harvest. The above-ground dry matter (AGDM) was divided into grains and residue. Yields were determined after drying at 105°C for 24 h. Yield components were determined including ear density, grains ear^{-1}, thousand kernel weight (TKW), grain density and single ear yield. Harvested grain were again divided into different fractions (< 2.2 mm, 2.2–2.8 mm, > 2.8 mm) by sieving, and shares of these fractions were expressed as percentages. For nitrogen (N) determination, grain and residue samples were first ground to pass through a 1 mm sieve. N concentrations were determined as an average of duplicate samples of about 50 mg each by the Dumas combustion method (Winkler et al., 2000), using an elemental analyzer (vario MACRO cube CNS; Elementar Analysensysteme GmbH, Germany). N yields of grain and residue were calculated by multiplying yields with N concentrations; based on these values, the N harvest index (NHI) was calculated. The N utilization efficiency (NUtE) was calculated according to Sinebo et al. (2004) as follows: NUtE ($g\ g^{-1}$) = YLD/NY_{AGDM}; where YLD is the grain yield or the AGDM yield and NY_{AGDM} is the N yield in the AGDM.

2.4 Statistics

The experiment was set up in a randomized complete block design with four replications. Statistical analyses were conducted using SAS software version 9.2. Analyses of variance (PROC GLM) with subsequent multiple comparisons of means were performed. Means were separated by least significant differences (LSD) when the F-test indicated factorial effects on the significance level of $p < 0.05$.

3. Results

3.1 Germination indices

Total germination did not differ between varieties; it tended to be higher with larger seed sizes as follows: < 2.5: 94.4%, 2.5–2.75: 94.9%, 2.75–3.25: 96.6% and > 3.25: 96.8% ($p = 0.096$). Mean germination time was significantly lower for Tatum (1.24 d) than for Paula (1.30 d) but did not differ between seed sizes.

3.2 Soil coverage

Timely emergence in 2012 resulted in an early start of soil coverage, whereas in 2013 for three weeks from the day of sowing, snow cover considerably delayed emergence, and thus, the start of the soil coverage. Consequently, at the end of April there was a mean soil coverage (over both varieties and all seed sizes) of 73% in 2012 but just 8% in 2013 (Figure 1A). Soil coverage was higher for Tatum than for Paula in May 2012 but did not differ on the other sampling dates in 2012 and in 2013.

Soil coverage was affected by seed size in 2012 alone; thus, results are shown for that year (Figure 1B). From early April till end of the month, soil coverage was ranked according to seed size with the highest values for > 3.25 (mm) and lowest for < 2.5 (mm). On 21st of May 2012, the two largest seed sizes resulted in higher soil coverage than the smallest seed size with 2.5–2.75 showing intermediate values.

3.3 Above-ground biomass yields and yield components

The main effects on biomass yields and yield components are shown in Table 2. Plant length at harvest was affected by variety × year: Paula was shorter than Tatum in 2012 with no differences between varieties in 2013 (2012: Paula – 52.4 cm, Tatum – 56,1 cm; 2013: Paula – 60.8 cm, Tatum – 60.6 cm; LSD = 2.6). The three-way interaction occurred as Tatum was taller with < 2.5 mm than for the other seed size in 2013 (data not shown).

Table 2. Yield and yield components of malting barley as affected by seed size, variety and year
Tabelle 2. Ertrag und Ertragsstruktur von Braugerste, beeinflusst von der Korngröße, der Sorte und dem Jahr

	Plant length	AGDM[1]	Grain yield	Residue	Harvest index	Ear density	Grains	TKW	Grain density	Single ear yield	Distribution of grain fractions (%)		
	(cm)	(g m^{-2})	(g m^{-2})	(g m^{-2})	(%)	(m^{-2})	(ear^{-1})	(g)	(m^{-2})	(g)	<2.2 mm	2.2-2.8 mm	>2.8 mm
Seed size													
<2.5	59.4^{a}	717	329	347	45.7	492^{b}	15.9	42.2^{a}	7795	0.671	3.8	62.4	33.5
2.5-2.75	56.9^{b}	744	340	359	45.4	540^{a}	15.1	41.4^{b}	8187	0.628	4.1	66.6	29.2
2.75-3.25	56.7^{b}	720	340	342	46.9	523^{a}	15.9	41.1^{b}	8272	0.654	3.9	66.0	30.0
>3.25	57.0^{b}	765	350	372	45.6	544^{a}	15.4	41.8^{ab}	8374	0.642	3.9	65.3	30.7
Variety													
Paula	56.6^{b}	717^{b}	326^{b}	350	45.3	533	15.5	39.4^{b}	8259	0.613^{b}	4.5^{a}	76.8^{a}	18.6^{b}
Tatum	58.3^{a}	756^{a}	353^{a}	359	46.4	517	15.6	43.9^{a}	8055	0.684^{a}	3.4^{b}	53.3^{b}	43.2^{a}
Year													
2012	54.3^{b}	725	306^{b}	419^{a}	41.9^{b}	528	14.4^{b}	40.4^{b}	7568^{b}	0.581^{b}	3.1^{b}	72.2^{a}	24.7^{b}
2013	60.7^{a}	748	373^{a}	291^{b}	49.9^{a}	522	16.8^{a}	42.8^{a}	8746^{a}	0.716^{a}	4.7^{a}	57.9^{b}	37.1^{a}
ANOVA GLM													
Seed size	*					**		*					
Variety	**	**	*					***		***	***	***	***
Year	***		***	***	***		***	***	***	***	***	***	***
S × V						*		*	*				
V × Y	**										***	***	***
S × V × Y	*												

[1] AGDM = Aboveground dry matter, [2] HI = Harvest index, [3] TKW = Thousand kernel weight. Different letters indicate significant differences. Significant effects: $p < 0.05$ (*), $p < 0.01$ (**) and $p < 0.001$ (***). Blank cells indicate that no significant differences were found. No S × Y interactions occurred.

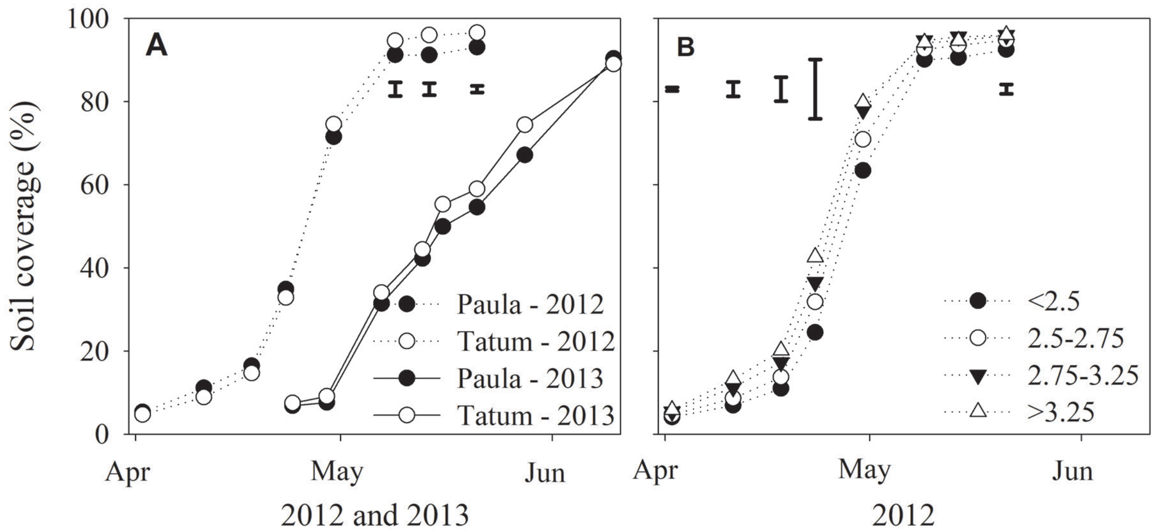

Figure 1. Soil coverage of malting barley as affected by (A) variety in 2012 and 2013 and (B) seed size in 2012. Error bars are LSD ($p < 0.05$).
Abbildung 1. Bodenbedeckung von Braugerste, beeinflusst von (A) der Sorte in den Jahren 2012 und 2013 und (B) der Korngröße im Jahr 2012. Die Fehlerbalken zeigen die Grenzdifferenz ($p < 0,05$).

Above-ground biomass (AGBM) and grain yield were higher for Tatum than for Paula. Grain yield was also higher in 2013 than in 2012. Both did not differ between seed sizes (although the highest values were observed with > 3.25 mm and lowest with < 2.5 mm; not significant). The residue yield was higher in 2012 than in 2013, and thus, the harvest index was lower in 2012. Both parameters were not affected by seed size and variety.

Ear density was affected by seed size × variety: For Paula, ear density was higher than for the other seed sizes with > 3.25 mm, whereas for Tatum, it was lower than for the other seed sizes with < 2.5 mm (Table 3). Grains ear^{-1} were higher in 2013 than in 2012, with no differences between seed sizes and varieties. The TKW of Paula was not affected by seed size, whereas it was for Tatum lowest with 2.5–2.75 mm and highest with < 2.5 mm and > 3.25 mm (Table 3).

Grain density of Paula was lowest for 2.5–2.75 mm and highest for > 3.25 mm (with other seed sizes showing intermediate values); TKW of Tatum was lowest with < 2.5 mm and highest with 2.5–2.75 mm (with other seed size factions showing intermediate values) (Table 3). Single ear yield was higher for Tatum than for Paula and higher in 2013 than in 2012.

Distribution of fractions of the harvested grains was as follows: The smallest fraction was the fraction < 2.2 mm for both varieties in both years, and the biggest was that with 2.2–2.8 mm. Grain fractions were not affected by

Table 3. Interaction of seed size × variety on ear density, thousand kernel weight (TKW) and grain density
Tabelle 3. Wechselwirkungen von Korngröße × Sorte auf die Ährendichte, das Tausendkorngewicht (TKW) und die Korndichte

Seed size	Ear density (m^{-2})		TKW[1] (g)		Grain density (m^{-2})	
(mm)	Paula	Tatum	Paula	Tatum	Paula	Tatum
< 2.5	520	464	39.9	44.6	8244	7346
2.5–2.75	525	556	39.8	42.9	7704	8670
2.75–3.25	525	520	38.9	43.3	8321	8223
> 3.25	562	526	38.9	44.6	8768	7980
$LSD_{0.05}$	41		1.2		1030	

Table 4. Interaction of variety × year on the harvested seed size fractions
Tabelle 4. Wechselwirkungen von Korngröße × Sorte auf die Korngrößenkategorien im Erntegut

	< 2.2		2.2–2.8		> 2.8	
	Paula	Tatum	Paula	Tatum	Paula	Tatum
	(%)					
2012	4.2	4.7	87.3	66.3	8.4	28.8
2013	2.0	4.7	57.1	49.6	41.0	45.4
$LSD_{0.05}$	1.1		7.8		8.6	

seed size but there was a variety × year interaction. The share of < 2.2 mm was similar for Tatum in both years but smaller for Paula in 2013 than 2012. The share of 2.2–2.8 mm dropped for both varieties in 2013 with a larger decrease for Paula. The share of > 2.8 mm increased for both varieties in 2013 with a larger increase for Paula (Table 4).

3.4 Nitrogen (N) concentrations, uptake and utilization efficiency

Grain and residue N concentrations, N yields of grain, residue and AGDM, the N harvest index and the NUtE did not differ between seed sizes (Table 5). The N yield of the AGDM was higher for Tatum than for Paula, whereas no

Table 5. Nitrogen (N) concentration, N yield and N utilization efficiency (NUtE) of malting barley as affected by seed size, variety and year
Tabelle 5. Stickstoffgehalt, -ertrag und -ausnutzungseffizienz (NUtE) von Braugerste, beeinflusst von der Korngröße, der Sorte und dem Jahr

	N concentration		N yield			NHI[1]	NUtE	
	Grain	Residue	Grain	Residue	AGDM		Grain	AGDM
	(%)		($g\ m^{-2}$)			(%)	($g\ g^{-1}$)	
Seed size								
< 2.5	1.90	0.60	6.20	2.09	8.29	74.3	39.7	87.5
2.5–2.75	1.76	0.62	5.94	2.23	8.17	71.9	41.9	93.0
2.75–3.25	1.82	0.61	6.15	2.11	8.26	74.1	41.0	87.7
> 3.25	1.83	0.62	6.40	2.28	8.67	73.2	40.5	89.4
Variety								
Paula	1.82	0.61	5.95	2.14	8.08[b]	73.1	40.4	89.8
Tatum	1.83	0.61	6.40	2.22	8.62[a]	73.7	41.2	89.0
Year								
2012	1.75[b]	0.62	5.28[b]	2.60[a]	7.88[b]	66.6[b]	38.8[b]	92.9[a]
2013	1.90[a]	0.60	7.07[a]	1.75[b]	8.82[a]	80.2[a]	42.8[a]	85.9[b]
ANOVA GLM								
Seed size								
Variety					*			
Year	**		***	***	***	***	***	*

[1] NHI = Nitrogen harvest index. Different letters indicate significant differences. Significant effects: p < 0.05 (*), p < 0.01 (**) and p < 0.001 (***). Blank cells indicate that no significant differences were found. No significant effects were found for two- and three-way interactions.

other differences among parameters between the two varieties occurred. Grain N concentration was higher in 2013 than in 2012; N concentration of residue did not differ between years. N yields of grain, residue and AGDM yield were also higher in 2013 than in 2012. Neither N harvest index nor NUtE for grain or AGDM production differed between seed sizes and varieties. N harvest index and NUtE for grain production were higher in 2013, whereas NUtE for AGDM production was higher in 2012 (Table 5).

4. Discussion

Total germination did not differ between seed sizes as also shown by others for spring malting barley (Rukavina et al., 2002) or winter wheat (Zareian et al., 2013). However, a tendency that larger seeds may enable a higher germination can be drawn from the results. Guberac et al. (1998) have shown for oat and Gross (1984) for six monocarpic perennial plants that larger seed size resulted in higher germination (due to the larger endosperm).

With increasing seed size, higher soil coverage occurred in the first year, probably due to higher emergence and/or higher early vigor of seedlings and plants emerging from larger seeds. A positive correlation of seedling growth with seed size (and seed N content) has been shown for maize (Krug, 1969). Soil coverage by plants is essential for radiation interception and for soil protection against erosion processes (Klima et al., 2016). Soil cover differs between crops and is affected by sowing date and winter survival of autumn sown crops (Neugschwandtner et al., 2015a, d). Similar to late sowing dates, a delay in emergence (as observed in the second experimental year) also considerably delayed full soil cover.

Seed size did not affect AGDM or grain yield, but grain yield differed between varieties and years. Among yield components, ear density and TKW but not grains ear^{-1} were affected by seed size. Both varieties had a higher ear density with the largest seed size compared to the smallest seed size. Aufhammer and Kübler (1987) have reported that for achieving a good yield, ear density is of higher importance whereas the number of grains ear^{-1} is of less importance for two-row barley than for six-row barley, and that complete grain yield compensation of low ear density by higher formation of spikelets is not possible. No differences occurred between seed sizes for grains ear^{-1}. Especially for two-row barley, higher ear densities might result in problems during grain filling and might impair TKW (Aufhammer and Kübler, 1987). This is supported by our observation that the medium seed size of Tatum (2.5–2.75), which produced the highest ear density, showed also the lowest TKW. Heyland and Triebel (1986) have reported for winter wheat that above average ear density may be compensated with both successively formed yield components, whereas with an ear density around average full compensation can already be achieved by only the next formed yield component, which is grains ear^{-1}. For winter wheat, sowing larger seeds resulted in better vegetative development (with faster field emergence and more tillers plant^{-1} but a less productive tillering – the combination of both resulted in no differences in ears plant^{-1} between seed sizes) and better reproductive development (with more fertile spikelets ear^{-1}, grains plant^{-1} and grain yield plant^{-1}) (Heyland and Scheer, 1984).

The aim of malting barley production is to produce large grains, which generally have a high starch and a low protein level (Fox, 2006). Specifically, Magliano et al. (2014) reported that thin grains have more protein than large grains when total grain samples had a low protein content, that is, when the sample came from an environment with a low relative abundance of nitrogen. We observed an interaction of variety × year for the harvested grain fractions but no effect of the size of sown seeds. In 2013, Paula had a higher increase of the > 2.8 fraction than Tatum compared to 2012. Contrary to our observations that harvested grain fractions are not affected by the size of the sown seed, several aspects influence grain size. Among those are genetic factors (Fox, 2006), environmental conditions, for example, drought and high temperature during grain filling decreased grain weight with a stronger effect of drought than temperature (Savin and Nicolas, 1996). Further, grain size increases with N fertilization, with a higher effect of splitting N doses than just increasing them (Aufhammer and Kübler, 1989). Heat stress may also increase grain N concentration (Passarella et al., 2008). In the drier and hotter year 2012, we observed a lower TKW and a higher share of small seeds but also lower grain N concentration.

Nitrogen concentrations and yields were not affected by seed size. No differences were observed for all assessed N parameters between varieties except for the N yield of the AGDM, which was higher for Tatum than for Paula. Between years, grain N concentration, N yield of grain, N harvest index and NUtE for grain production were higher in 2013 than in 2012. Differences between years for these parameters have already been reported for barley as well as pea and oat (Neugschwandtner et al., 2015c) as both the absolute and relative crop growth rates (Neugschwandtner et al., 2013) and nitrogen uptake rate and the relative nitrogen uptake rate (Neugschwandtner et al., 2014) differed between years as growth processes are influenced by environmental conditions (temperature, solar radiation, water and nutrient supply) (Connor et al., 2011).

5. Conclusion

In one year, seed size increased soil coverage. Aboveground biomass and grain yield were not affected by seed size. Larger seed size increased ear density, but with higher ear density, the TKW decreased. Seed size did not affect harvested grain size fractions or nitrogen concentrations and nitrogen yields.

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