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Are specific testing protocols required for organic onion varieties? Analysis of onion variety testing under conventional and organic growing conditions

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Abstract Organic growers need information on variety performance under their growing conditions. A 4-year onion variety research project was carried out to investigate whether setting up a variety testing system combining conventional and organic variety trials is feasible and efficient rather than organizing separate variety trials under the two management systems. During 4 years commercial onion cultivars were tested at a certified organic and a non-organic location. Both systems were managed without chemical pest, disease and sprouting control, but differed in fertility management (organic manure in autumn versus synthetic fertilizer), soil cultivation and weed management (mechanical weeding versus application of herbicide). Management system significantly affected plant density, thickness of neck, and proportion of small and large bulbs. Variety × management system interactions were significant for bulb uniformity, earliness, proportion of large bulbs, dormancy and relative storage success but did not change the ranking of the varieties. We conclude that organic growers can profit from a more conscious variety choice when conventionally fertilised trials would refrain from using pesticides, fungicides, herbicides and sprout inhibitors. However, this would require an adaptation of the management protocol in such a way that trials might no longer represent conditions of conventional farmers. Furthermore, assessments of leaf erectness, disease resistance to downy mildew and leaf blight should be included in the protocols for organic use. We advocate better communication between breeders and growers on specific variety characteristics contributing to improving yield stability under low-input, organic growing conditions.

Keywords Onion · Organic agriculture · Variety testing

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Introduction

In organic farming in the Netherlands, onion (*Allium cepa* L.) is one of the most important vegetable crops. The total area of organic onion production expanded from 177 ha in 1995 to 716 ha in 2003 and since then declined to about 480 ha in 2009 (CBS 2009). More than 80% of the produce is exported. Yields of onion production can differ substantially between conventional and organic farming systems in the Netherlands. They range from 50–100 Mg ha^{-1} for conventional conditions to 25–60 Mg ha^{-1} for organic conditions. In years with severe infestation of downy mildew (*Peronospora destructor*) yields can even be lower under organic conditions as there are no appropriate means to protect the crop other than growing resistant cultivars. In 2007, the first two resistant varieties resulting from conventional breeding programmes were released and grown by organic growers (Scholten et al. 2007). Lower onion yields in organic farming systems are also caused by lower levels of nitrogen input (approx. 40–50%) in organic than in conventional farming. Moreover, organic fertilizers are known for their slow release of nitrogen early in the growing season. Some organic growers are inclined to sow later (beginning of April instead of March) than their conventional colleagues to allow the soil temperature to rise resulting in a higher and more uniform germination and better nitrogen availability. Many research projects in the Netherlands have focussed on optimising organic onion production in terms of yield and bulb size distribution to better cope with mechanical weed management and to reduce disease pressure from downy mildew (Van den Broek 2004, 2005, 2008).

To avoid crop failure, growers also have to be very demanding regarding the varieties they select to grow. Desired traits for organic production in general and more specifically for onion cultivation, such as leaf erectness for less damage during mechanical weed control, have been identified (Lammerts van Bueren et al. 2002, 2005; Osman et al. 2008). Organic growers need relevant information on variety performance under low-input, organic growing conditions as sometimes the performance of varieties under organic management differs from that under conventional conditions as Murphy et al. (2007) showed for cereals. In some countries, such as Austria, the government financially supports an organic testing protocol for assessing the Value for Cultivation and Use for cereals in addition to the conventionally managed trials (Löschenberger et al. 2008; Rey et al. 2008). Most official variety trials in the Netherlands, including those for onion, are no longer financed by the government but by a consortium of growers, breeders and seed traders. As onion is an important export crop, the conventional sector organises regular variety trials. However, the Dutch organic sector is too small to finance separate organic variety trials and is searching for cheaper options, e.g. by modifying the conventional onion testing protocol in ways that would give better information for both management systems. Therefore, the Dutch government financed a research programme from 2001 to 2004, aiming to compare onion variety trials carried out under conventional and organic growing conditions to provide answers to the following three questions:

1. Which traits are relevant to include in protocols of conventional onion variety trials to assess the suitability of varieties for cultivation under organic growing conditions?
2. To what extent can conventionally managed trials without pest and disease control, including traits relevant for organic farming systems, provide good information for the performance of varieties under organic growing conditions?
3. For which traits relevant for organic agriculture is the performance of the existing varieties inadequate to contribute to yield stability, and is there a need for variety improvement in that respect?

Materials and methods

General methodology

Each year 14–20 modern onion varieties were tested under conventional and organic growing conditions, from 2001 to 2004. In contrast to the current practice, for this project the conventional trials were managed without chemical pest, disease and sprouting control (hereafter named ‘non-organic’) to assess varietal differences in disease resistances and to analyse whether non-organic variety trials can provide useful information for organic growers. For more details of the crop management in the trials, see Table 1.

The field experiments were established in two of the most important areas for onion production in the Netherlands: Flevoland (situated in the centre) and Zeeland (located in the southwest). Only in 2001, the organically managed trial was located in Flevoland (Nagele) on an organic certified experimental farm. The non-organic trial was located at the experimental station of Wageningen University and Research Centre (Lelystad), at 30 km distance from each other. In the subsequent years, experiments were carried out in Zeeland, with the non-organic trials conducted on the experimental station Rusthoeve (Colijnsplaat), and the organic trials on a certified organic farm in IJzendijke, again at about 30 km from each other.

From 2002 to 2004 the onion varieties were directly sown in April. Only in 2001 sowing had to be postponed until early May due to extreme rainfall in April. All cultivars were harvested at the same date, early September. For each variety, seeds for the two management systems came from the same source and were conventionally produced without chemical post harvest seed treatments. When organically produced seed was available, organic seed was used for both management systems, see Table 2. In 2001, seed of one variety was only available after a priming treatment. Seed priming to stimulate rapid and even germination is permitted in organic agriculture when only a clay mixture without addition of chemical seed treatment with fungicides is applied. For all seed lots the germination rate was obtained from the seed companies and these data were used to correct, if necessary, the standard sowing rate of 100 seeds m^{-2}.

For all trials the net plot size was 1.5 × 8 m, with a row distance of 0.27 m (5 rows per 1.5 m bed). To evaluate storability the onions were stored by ambient air ventilation until approximately mid February/beginning of March at a temperature of 3–4°C.

Variety choice

The choice of varieties was determined yearly together with the stakeholders involved: organic growers, seed companies and researchers. The budget of the project allowed 14–20 varieties per year to serve on the one hand the wish of the organic growers and seed companies to observe the performance of the latest, most promising varieties suitable for the Dutch organic, low-input conditions and on the other hand to guarantee some level of scientific rigour of the research programme by including at least a core group of varieties for all 4 years, see Table 2.

Criteria for evaluation

The criteria to evaluate the suitability of varieties to be grown under organic conditions were identified in a participatory process with a group of 30 organic onion growers (Lammerts van Bueren et al. 2005; Osman et al. 2008). Specific criteria for field evaluation during the growing season were added to the criteria regularly applied in current conventional onion variety trials (Table 3).

Statistical analysis

The experimental design consisted of 4 years with two locations per year of which one location was treated as non-organic and the other as organic. Within each location a completely randomised block design was performed with three replicates and a variable number of varieties. The analysis for this paper was based on the results of those 16 varieties that had been included in the trial for at least 2 years (Table 2).

To take into account that the management system (non-organic versus organic) was only replicated at location level an analysis was performed with year and location within year as random terms and management system, variety and their interaction as fixed terms in the model. Restricted maximum likelihood (REML) method was used to estimate the fixed and random effects.

All results and conclusions presented in this paper are based on the Wald test. All analyses were performed in the statistical package GenStat. The REML analysis also resulted in (predicted) means for each variety-management system combination that were comparable and corrected for differences due to year and location. These means were used to calculate the Spearman rank correlation to test whether the ranking of the varieties was different between the two management systems.

Results

Field traits

In all four experimental years the non-organic fields showed on average a statistically lower number of

Table 1 Details on the crop management of the non-organic and organic trial fields, 2001–2004

	Non-organic	Organic
Soil texture	Clay	Clay
Silt fraction (%)		
2001	21	30
2002	20	33
2003	33	36
2004	18	33
pH soil		
2001	7.6	7.5
2002	7.4	7.6
2003	7.4	7.4
2004	7.5	7.7
Soil organic matter (%)		
2001	1.8	2.4
2002	1.9	2.1
2003	1.9	2.5
2004	1.8	2.4
P_2O_5 (mg/100 g)		
2001	30	15
2002	34	26
2003	39	36
2004	25	39
K_2O (mg/100 g)		
2001	20	19
2002	31	26
2003	26	29
2004	20	26
Preceding crop		
2001	Spring barley	Grass/clover
2002	Spring wheat	Spring wheat with clover
2003	Sugar beet	Spring wheat
2004	Spring barley	Sugar beet
Fertilisation for onion	Mineral fertilisers	Organic fertilisers
2001	370 kg KAS (100 kg N/ha)	20 tonnes goat manure (65 kg available N/ha)
2002	410 kg KAS (110 kg N/ha)	24 tonnes goat manure (65 kg available N/ha)
2003	410 kg KAS (110 kg N/ha)	24 tonnes goat manure (65 kg available N/ha)
2004	440 kg KAS (120 kg N/ha)	24 tonnes goat manure (60 kg available N/ha) + 1.5 tonnes vinasse potassium (60 kg available N/ha) in spring
Time of fertilisation	Before seed bed preparation in spring	In autumn before ploughing (goat manure)
Weed management	Chemical	Mechanical (1–5 ×)
	After sowing before emergence 1.5 l/ha Stomp; after first real leaf appearance 0.25 Basagran + 0.25 Actril	
Pest and disease management	None	None

Table 2 Overview of the 16 onion varieties evaluated for at least 2 years in the variety trials 2001–2004

Variety	Variety type[a]	2001	2002	2003	2004	No. of years in trials	Origin
Yellow onion							
Canto	F1			X	X	2	Nickerson-Zwaan
Hytech	F1		X	X		2	Bejo Seeds/De Groot & Slot
Napoleon	F1		X		X	2	S&G Seeds/Syngenta
Wellington	F1		X		X	2	S&G Seeds/Syngenta
Arenal	F1		X	X	X[b]	3	Advanta Seeds/Nickerson-Zwaan
Hystar	F1	X[b]	X[b]	X[b]		3	Bejo Seeds/De Groot & Slot
Baldito	F1	X	X	X	X	4	Seminis/Monsanto
Drago	F1	X	X	X	X	4	Nickerson-Zwaan
Hyfort	F1	X[c]	X	X	X[b]	4	Bejo Seeds/De Groot & Slot
Hyskin	F1	X	X	X	X	4	Bejo Seeds/De Groot & Slot
Profit	F1	X	X[b]	X[b]	X[b]	4	Advanta Seeds/Nickerson-Zwaan
Sunskin	F1	X	X	X	X	4	S&G Seeds/Syngenta
Balstora	OP	X	X	X	X	4	Bejo Seeds/De Groot & Slot
Red Onion							
Red Kite	F1	X	X			2	Seminis/Monsanto
Redspark	F1		X	X	X	3	Bejo Seeds/De Groot & Slot
Red Baron	OP	X		X	X	3	Bejo Seeds/De Groot & Slot
Total no. of varieties/year		10	14	13	13		

[a] *F1* hybrid variety, *OP* open pollinated variety

[b] Organically produced seed

[c] Primed seed

plants (78 plants m^{-2}) than the organic fields (91 plants m^{-2}). As seed from the same seed lot was used for both non-organic and organic trials, and as the sowing dates did not differ substantially, the lower densities under non-organic management were most likely associated with seedling damage caused by the application of herbicides. However, also other differences in soil cultivation and growing conditions could have influenced plant density. As plant density often affects earliness of bulb development, bulb-size distribution and, therefore, marketable yield, plant density should always be assessed in onion variety trials, whether they are non-organic or organic. Correcting for variation in plant density might be possible for some variables (e.g. yield) but is complicated for other ones (e.g. bulb size distribution). The low values for the rank correlation coefficients between non-organic and organic trials for plant density suggest that in non-organic trials the application of herbicides influenced the plant density differently per variety and this complicates any extrapolation to performance under organic conditions, see Table 4 and Fig. 1a. So the non-organic trial gave a poor prediction of the ranking of varieties for plant density in the organic trials. This has also consequences for the prediction of yield, bulb size distribution and earliness.

The gross yield assessed at harvest time showed genetic variation, and especially the red varieties yielded on average lower than the yellow onions. We also assessed a large variation among years due to different weather conditions and downy mildew infestations. On average, the gross yield was lower under organic growing conditions (44.7 Mg ha^{-1}) than under non-organic conditions (53.9 Mg ha^{-1}), see Table 4 and Fig. 1b. Although in 3 of the 4 years the yield differences between organic and the non-organic fields were statistically significant, the overall difference was not significant (Table 5). The average reduction in yield was 17.0%. Given the chemical crop protection in the common conventional practice, the differences in yield between the two farming systems will be larger in practice. The non-organic and organic trials suffered from a severe downy

Table 3 Criteria included in the variety trials for the evaluation for organic farming in 2001–2004

	Evaluation method
In the field	
Plant density	Number of plants m^{-2}
Earliness	Days from sowing to 50% of leaf fall down
Uniformity crop stand[a]	1–9 (1 = very low, 9 = very high)
Leaf erectness[a]	1–4 (1 = planophile, 2 = intermediate, 3 = erect, 4 = very erect)
Leafiness[a]	1–9 (1 = very few, 9 = large amount of leaves)
Dead leaf tips[a]	1–9 (1 = large number and large proportions, 9 = very few and little)
Leaf colour[a]	1–3 (1 = green, 2 = bluish-green, 3 = blue)
Downy mildew[a] (*Peronospora destructor*)	1–9 (1 = all leaves severely infested, 9 = no infestation)
Leaf blight[a] (*Botrytis squamosa allii*)	1–9 (1 = all leaves severely infested, 9 = no infestation)
At harvest	
Gross yield	Yield of net plot area (8 × 1.5 m)
Uniformity bulb	1–9 (1 = very low, 9 = very high)
Thickness of neck	1–9 (1 = very thick, 9 = very fine)
Bulb shape	1–9 (1 = very flat, 6 = round, 9 = rhombic)
After storage	
Good bulbs	% unaffected bulbs of total weight including bulbs with no or too few skins, but excluding rotten and sprouted bulbs
Bulb size distribution	% bulbs of good bulbs in the classes: < 40 mm, 40–50 mm, 50–70 mm, > 70 mm
Portion marketable	% weight of good onions bulbs > 40 mm of total weight after storage
Firmness of bulbs (1)	As measured by penetrometer (30 onion bulbs in the class 40–60 mm)
Firmness of bulbs (2)	Based on rating; score of 100 is average
Relative storage success	% good bulbs of a specific variety divided by the average % good bulbs across all tested varieties. A higher figure meant a better output
Dormancy	Day number on which 50% has sprouted

[a] Upon request of organic farmers these traits were added to the protocol for non-organic onion variety trials

mildew incidence in 2002 (see Table 6) and from a mid- and late season drought in 2003. The average yields in the 3 years with moderate to low downy mildew incidence (2001, 2003 and 2004) gave an indication for an average yield difference between organic and non-organic conditions, which in our trials showed a maximum of 30.9% (Table 5). The overall comparison showed that there were significant differences amongst varieties but not between the management systems; moreover no significant interaction was observed. The Spearman correlation showed a good rank correlation between the results from the non-organic and organic trials, see Table 4 and Fig. 1b. This means that in this data set the non-organic trials provided a good prediction of the ranking of organically grown varieties with respect to their yielding capacity.

Organic growers prefer varieties with an erect leaf attitude to avoid leaf damage during mechanical weed control. Varieties with more leaf mass are considered more stress resistant in dry periods and more productive. Varieties without dead leaf tips during early crop growth might indicate more regular growth and less sensitivity to stress. For these three leaf characteristics we observed significant variety differences ($P < 0.001$), but no effects of farming system or significant Variety × Management interactions (Table 4).

The main disease that occurred during these trials was downy mildew (*Peronospora destructor*). Especially in 2002 yields in both non-organic and organic experiments were severely affected by this disease, see Table 6. In most trial years downy mildew started late and was slightly less severe under organic conditions than under non-organic conditions (without disease

Table 4 Mean values and analysis of variance on the performance per trait (P values) in the variety trials under non-organic and organic conditions across the 4 years (2001–2004), and the Spearman rank correlation (r_s) with probability between the two management systems (non-organic and organic), based on the average per variety, 2001–2004

Traits	Mean values (min.-max.)		Differences between non-organic and organic	Variety	Interaction	Spearman rank correlation
In the field	Non-organic	Organic	P-value	P-value	P-value	r_s value
Plant density	77.7 (69.9–84.6)	90.7 (85.3–97.0)	0.025	<0.001	0.093	0.324
Earliness	6.0 (5.1–6.6)	6.6 (5.7–7.1)	0.160	<0.001	0.050	0.632**
Uniformity crop stand	6.7 (6.2–7.4)	6.8 (6.4–7.3)	0.467	<0.001	0.518	0.576**
Leaf erectness	6.4 (5.1–7.7)	6.5 (5.1–7.5)	0.696	<0.001	0.804	0.929***
Leafiness	7.2 (6.8–7.5)	7.3 (6.8–7.9)	0.658	<0.001	0.206	0.129
Dead leaf tips	5.9 (5.1–6.3)	6.1 (5.5–6.6)	0.446	<0.001	0.243	0.400*
Leaf colour	7.1 (6.1–7.8)	7.0 (6.0–7.7)	0.344	<0.001	0.832	0.879***
Downy mildew	5.4 (4.0–6.0)	5.8 (4.8–6.4)	0.688	<0.001	0.671	0.698***
At harvest						
Gross yield	53.9 (46.6–57.3)	44.7 (38.2–49.9)	0.192	<0.001	0.808	0.732***
Uniformity bulb	6.1 (5.7–6.5)	6.4 (5.5–7.0)	0.082	<0.001	0.017	0.482*
Thickness of neck	6.1 (5.7–6.4)	6.6 (6.2–7.1)	0.031	<0.001	0.579	0.837***
Bulb shape	6.3 (6.0–6.8)	6.5 (6.0–7.1)	0.358	<0.001	0.092	0.632**
After storage						
Proportion bulbs < 40 mm	7.8 (5.3–12.2)	16.5 (11.1–23.5)	0.054	<0.001	0.147	0.565**
Proportion bulbs 40–50 mm	21.7 (17.6–31.3)	35.9 (27.0–42.9)	0.005	<0.001	0.317	0.774***
Proportion bulbs 50–70 mm	50.1 (35.7–57.3)	34.6 (19.6–41.8)	0.302	<0.001	0.811	0.774***
Proportion bulbs > 70 mm	10.7 (2.5–15.5)	1.0 (0.5–2.2)	0.343	<0.001	<0.001	0.671**
Portion marketable	83.5 (63.5–89.8)	71.4 (45.9–78.8)	0.161	<0.001	0.469	0.747***
Firmness of bulbs (1)	199.5 (176.1–335.4)	191.3 (170.4–290.2)	0.318	<0.001	0.353	0.694***
Firmness of bulbs (2)	101.0 (74.5–111.4)	101.5 (79.0–111.9)	0.746	<0.001	0.746	0.938***
Relative storage success	99.7 (93.5–102.6)	98.7 (80.1–106.3)	0.557	<0.001	0.006	0.582**
Dormancy	28.4 (–8.9–112.3)	18.7 (–8.7–62.8)	0.326	<0.001	0.013	0.768***

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

treatment), see Table 6, but eventually hit the yield in a dramatic way under both management regimes. There were significant variety effects ($P < 0.001$). There were no significant management system effects nor was the Variety × Management interaction statistically significant (Table 4). There was a good rank correlation between the (not treated) non-organic and organic trials ($r_s = 0.70$), so that the results of non-organically managed trials without fungicides may be used to predict differences in susceptibility of varieties for downy mildew under organic conditions.

Organic growers aim at a crop that can escape disease through earliness, has a high yield and a well storable product without using chemical sprouting inhibitors; therefore they require, like their conventional counterparts, a mid-early variety that matures in less than 127 growing days. There were significant varietal differences in earliness ($P < 0.001$), both under organic and non-organic conditions. We found a positive rank correlation ($r_s = 0.63$) between organic and non-organic trials, see Table 4. However, we also found a significant interaction effect ($P = 0.05$), suggesting that results of conventional trials cannot be used to predict earliness under organic conditions. Earliness may be associated with higher plant density which stimulates early maturing. As the higher plant density in the organic

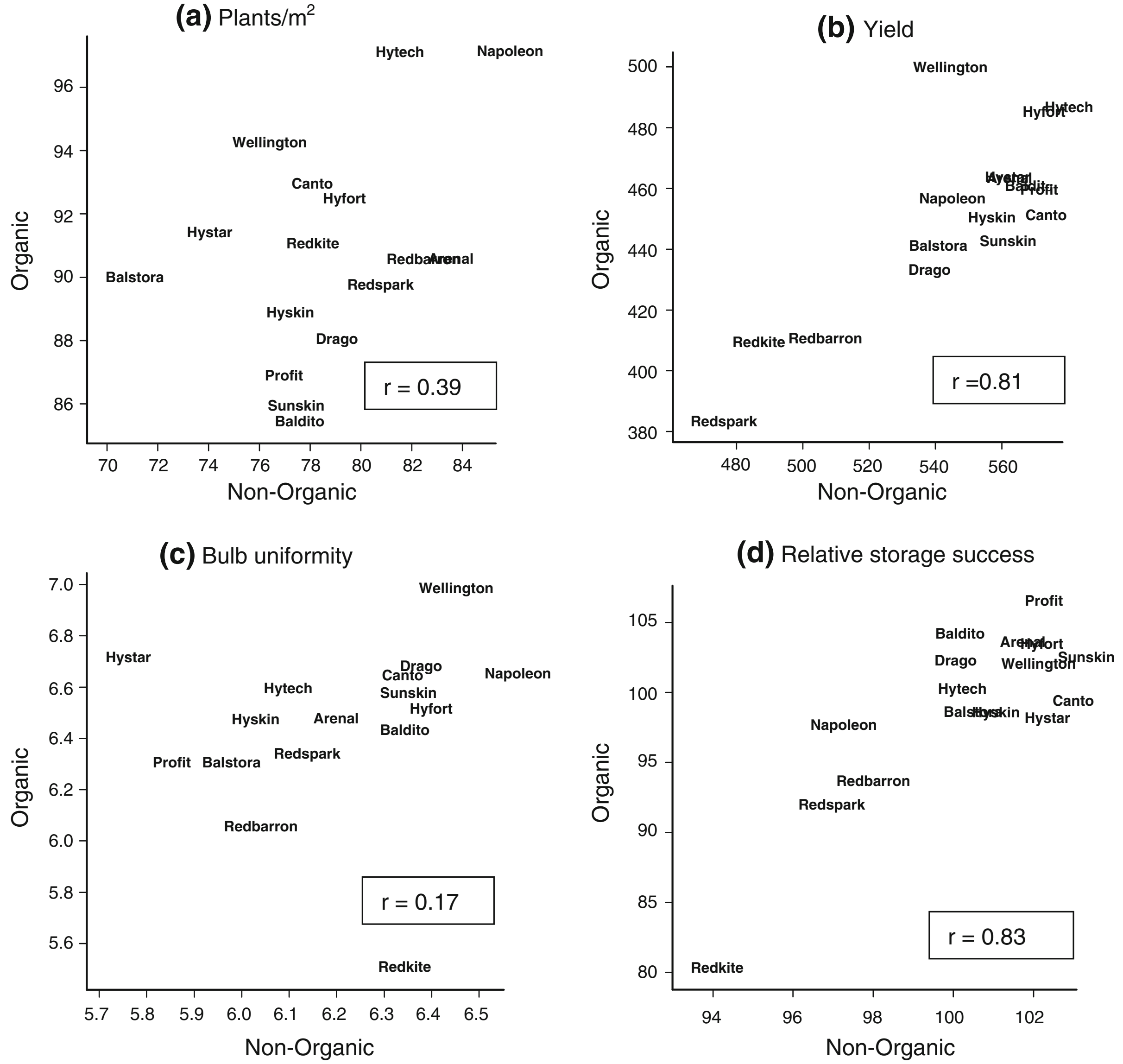

Fig. 1 Correlation (r) between evaluation results of the organic versus non-organic trials with 16 onion varieties for (**a**) plants/m^2, (**b**) gross yield, (**c**) bulb uniformity and (**d**) relative storage success, over the period 2001–2004

Table 5 Comparison of the average yields (Mg ha^{-1}) of 16 onion varieties grown under non-organic and organic conditions in trials carried out in the period 2001–2004

	2001	2002	2003	2004	Average over 4 years
Non-organic Lelystad/Colijnsplaat	77.6	41.6	27.8	68.9	53.9
Organic Nagele/IJzendijke	53.6	38.6	28.9	58.0	44.7
Yield reduction under organic %	30.9	7.2	-4.0	15.8	17.0
P value	<0.001	<0.001	0.200	<0.001	
S.e.d[a]	0.83	0.83	0.86	1.29	

[a] Standard error of difference of means

Table 6 Comparison of the average score[a] for downy mildew tolerance of 16 onion varieties grown under non-organic and organic conditions in trials carried out in the period 2001–2004

Variety name	2001		2002		2003		2004		Average over 4 years[b]	
	Non-org	Org	Non-org	Org	Non-org	Org	Non-org	Org	Non-org	Org
Arenal			3.7	5.7	9.0	7.7	6.3	5.3	5.8	6.3
Baldito	5.0	6.7	3.7	5.3	9.0	6.7	6.0	5.2	5.9	6.0
Balstora	4.5	6.5	4.5	5.3	8.7	6.7	6.3	7.0	6.0	6.4
Canto					9.0	6.3	5.2	4.7	5.4	5.1
Drago	4.0	5.7	3.0	5.2	9.0	7.3	6.3	6.0	5.6	6.0
Hyfort	3.7	6.2	3.7	4.7	9.0	7.3	6.3	5.3	5.7	5.9
Hyskin	5.0	6.2	3.7	4.2	9.0	7.3	6.0	4.5	5.9	5.5
Hystar	4.3	6.5	3.7	4.8	9.0	7.0			5.7	5.9
Hytech			4.2	6.2	9.0	7.0			5.9	6.4
Napoleon			2.7	4.0			5.3	5.0	5.2	5.3
Profit	4.7	6.7	4.2	4.8	9.0	8.3	4.7	5.5	5.6	6.3
Redbarron	3.0	5.8			9.0	7.0	4.0	4.0	4.7	5.3
Redkite	2.3	5.7	2.3	4.7					4.0	5.5
Redspark			3.0	4.5	8.0	6.7	3.7	3.2	4.4	5.9
Sunskin	3.5	5.8	3.8	4.8	9.0	9.0	6.3	6.0	5.6	6.4
Wellington			2.7	4.5			5.0	4.0	5.0	5.1
Mean	4.0	6.2	3.5	4.9	8.9	7.3	5.5	5.1	5.5	5.9
P value	<0.001		<0.001		<0.001		0.043		0.688	

[a] 1 all leaves severely infested, 9 no infestation

[b] average over 4 years is based on the REML-model, i.e. averages corrected for missing years

trials may have confounded our results, further research would be required to confirm our findings.

We also included the characteristics leaf blight, leaf colour and crop stand uniformity in the evaluation. Leaf blight did not occur in the years of the trials, so we cannot conclude whether results of non-organic, non-treated variety trials will give a good prediction for this trait under organic conditions. Farmers expected that leaf colour would differ under low fertilizing conditions and could be an indicator of not being able to cope with low nitrogen availability. For both leaf colour and crop uniformity variety differences were significant ($P < 0.001$), but there were no significant treatment effects or Variety × Management interactions, nor any correlations with other traits, see Table 4. The non-organic trials gave a good prediction of performance of leaf colour and crop uniformity under organic conditions.

Harvest traits

The bulb-size distribution can be influenced by variety and by management (e.g. sowing date, plant density, fertilisation, control of weeds, pests and diseases). The markets for both organic and conventional onions prefer the bulb size class 50–70 mm. Varieties differ significantly in their bulb-size distribution. Bulbs smaller than 40 mm cannot be sold. Especially organic growers want to avoid the risk of a too high rate of bulbs smaller than 40 mm, which is more likely under organic conditions as the fraction of large bulbs is closely correlated to total bulb yield and thus to nitrogen availability. As expected, under organic conditions a significantly larger proportion of bulbs were smaller than 40 mm (16%) than under non-organic conditions (8%). The organic trials also had a significantly larger proportion of bulbs in the size class 40–50 mm than the non-organic trials. These differences were most likely associated with differences in plant density (Table 4) and/or fertilisation level. The non-organic and organic trials showed a good rank correlation for bulb sizes, see Table 4. For the largest class (>70 mm) we found a significant Variety × Management interaction ($P < 0.001$).

Bulb uniformity is demanded by the market. The difference in average uniformity in bulb size was not significantly ($P = 0.08$) higher under organic (6.4) than under non-organic conditions (6.1). However, varieties differed significantly ($P = 0.01$) for this trait under organic conditions, but under non-organic conditions there were no significant differences ($P = 0.08$) among the tested varieties. The trials showed an interaction effect ($P = 0.02$), and a low rank correlation ($r_s = 0.48$) between the results of the organic and non-organic trials, see Fig. 1c. This means that non-organically managed trials including the use of herbicides cannot give reliable information on bulb uniformity for organic growers.

A finer neck is needed to allow the foliage to fall down easier at maturation time and the neck will dry easier thus preventing moulding during storage. Onions harvested from the organic fields showed a significantly larger proportion of smaller sized bulbs and therefore probably also finer necks than the non-organically grown ones ($P = 0.031$), see Table 4. Varieties differed significantly in producing thick necks. The trials showed a good ranking correlation ($r_s = 0.84$) between the results under organic and non-organic trials. So the non-organic trials can be used to predict the thickness of necks of the varieties grown under organic circumstances.

Storage quality traits

The decisive traits for both conventional and organic growers are the traits related to the quality and thus the marketability of the bulbs after storage, such as loss in bulb weight, skin retention, healthy (unaffected) bulbs, % marketable bulbs, % waste, firmness of bulbs, relative storage success and dormancy. For organic growers dormancy is more important than for conventional growers as the last group can compensate lack of dormancy with chemical sprouting inhibitors. For all these traits the differences between the varieties were small, although significant. Nevertheless the trials showed an interaction effect on the dormancy ($P = 0.01$), mostly due to one variety (Wellington) which had by far the best dormancy especially under non-organic conditions. Also for the relative storage success there was a significant interaction ($P = 0.006$). Under organic conditions there was more variation among the varieties than under non-organic conditions. Some varieties (mostly the red types) showed a lower relative storage success under organic conditions than under non-organic conditions, see Fig. 1d.

On the one hand one could conclude that the trials with this set of varieties show a good correlation between the results of the organic and non-organic trials for all storage quality traits (see Table 4), suggesting that organic growers can rely on the variety differences and ranking resulting from conventional trials. However, as the trials also showed significant Variety × Management interaction but no ranking differences, trials with another set of varieties could possibly result in a change in ranking.

Discussion

Which traits are relevant to include in the protocol of onion variety trials to evaluate the suitability of varieties for organic growing conditions?

Besides the traits that are normally evaluated in conventionally managed onion variety trials, organic farmers have requested to investigate some extra criteria concerning the field performance of onion varieties: crop canopy uniformity, leaf erectness, leafiness, dead leaf tips, leaf colour, resistance to downy mildew (*Peronospora destructor*), and resistance to leaf blight (*Botrytis squamosa allii*) (Table 3). For all these traits we found varietal differences in our trials (except leaf blight which did not occur). For crop canopy uniformity, leafiness, and leaf colour we did not find clear evidence for correlations with other traits such as yield. Therefore, in our opinion, these traits are not relevant to include as predictors for stress resistance, yield and/or the other tested traits. For dead leaf tips the varieties showed significant differences. However, more research would be needed to show that dead leaf tips are an indicator for low stress resistance and would therefore be a useful trait to add in variety testing. Leaf erectness is important to avoid damage by mechanical weeding; this research showed significant genotypic differences. Also for resistance to downy mildew organic growers made clear that this is an important trait for their variety choice. The differences in field tolerance between (non-resistant) varieties found in our trials were not large enough to be effective in practice during severe incidences, although in years with less severe disease pressure less susceptible varieties can keep up longer and can provide an economically acceptable yield. Resistance or tolerance to downy mildew of a variety (in combination with earliness) does add important information for the growers to make better informed decisions concerning variety choice. At the time of the trials resistant varieties were not yet on the market, but when in 2007 two resistant varieties entered the market seed demand of these varieties by organic growers was higher than seed availability in the following years (pers. comm. F. Van de Crommert, 2010). An effect of including additional traits such as downy mildew resistance in variety testing protocols might be that breeders would pay more attention to resistance during selection, which could be beneficial both to conventional and organic varieties in the future.

Although differences in susceptibility in leaf blight are also relevant to growers, in the years of this research we could not assess this trait and cannot confirm significant varietal differences for this trait.

In conclusion, leaf erectness, resistance to downy mildew and leaf blight are important additional traits to be added to the protocol of variety testing.

To what extent can conventionally managed trials without disease control provide good information on the performance of varieties under organic growing conditions?

We first have to stress that the results described above are influenced by the assortment of 16 varieties selected for the tests of which most were Rijnsburger types, the main genetic background of the current varieties on the Dutch market. We also stress that the fertility level of the Dutch clay soils is relatively high compared with the soil fertility level in other countries. This means that the results can differ when other varieties are included and tested under lower levels of fertility.

Literature on comparing results of variety testing under organic and conventional conditions of other crops than onions show in some cases that the ranking of varieties is the same and sometimes can differ between both growing conditions depending on the evaluated trait, the included variety assortment and fertility level of the test locations (Murphy et al. 2007; Lorenzana and Bernardo 2008; Przystalski et al. 2008; Vlachostergios and Roupakias 2008). No relevant references were found on onion. Our trials, comparing the performance of onion varieties under organic and non-organic growing conditions, showed system effects for plant density, thickness of neck, and small bulb size proportions. Interaction effects for important traits such as bulb uniformity, earliness, proportion of large bulbs, dormancy and relative storage success were found. However, for most traits this did not lead to differences in ranking of the varieties. The trials showed a good correlation between the results under organic and non-organic conditions except for plant density and leafiness. A moderately significant correlation occurred for dead leaf tips and bulb uniformity.

A number of important traits showed interaction (earliness, bulb uniformity, proportion of bulbs >70 mm, relative storage success and dormancy). From literature it is known that the number of plants emerging after sowing is strongly influenced by the (early) sowing date, sowing density, seed germination rate, management and weather conditions (Brewster 1994). It is also known that herbicides can reduce crop establishment in onions and herbicide effects can differ per variety (Brewster 1994; Hoek and Van den Broek 2002). As the application of herbicides in the non-organic trials influences the plant density differently per variety it complicates the extrapolation from a non-organic trial with use of herbicide to the performance under organic conditions. In conventional onion variety trials differences in plant densities between varieties do occur regularly. In that case yield may be corrected for number of plants m^{-2}; however normalizing traits like bulb-size distribution and earliness is not possible in this way.

The criteria leaf erectness and susceptibility to downy mildew are important for organic growers and for these traits the conventional trials without disease control showed a good correlation with organic trials. If organic growers want to assess the differences in susceptibility to diseases such as downy mildew they have to urge for a ‘non-treated’ trial in regions with high natural disease pressure.

The high input conditions of non-organic trials gives a shift in bulb-size distribution to larger sizes compared to organic trials. Although organic growers want to avoid thick necks correlated with large bulb sizes as this affects the storability, they are even more concerned about the risk of too large proportions of unmarketable bulbs smaller than 40 mm. Although there was an interaction effect, it did not lead to different ranking of the varieties for this trait. The conclusion is that non-organically managed trials provide sufficient information to organic growers when leaf erectness and susceptibility to downy mildew and leaf blight are included.

For which traits of importance for organic agriculture is the level of performance among the current varieties not high enough to contribute to yield stability and is there a need for variety improvement for organic agriculture?

Our research showed that in a year with downy mildew infestation yields can be reduced dramatically. The organic sector is already very positive about the recent availability of downy mildew resistant varieties. However, this resistance is a monogenetic trait based on the only available resistance gene (Scholten et al. 2007). To reduce the risk of break down during too long exposure of downy mildew and to support the escape management, organic growers would benefit from the combination of earliness and resistance to downy mildew. Osman et al. (2008) reported that some breeders pay attention to leaf erectness as they assume that such leaf attitude can show better drainage and might support field tolerance to leaf diseases. However, this supposed effect could not be confirmed by our trial results, nor by Van den Broek (2004, 2005). Nevertheless leaf erectness remains important for reasons to avoid damage during mechanical weeding. Our research shows that the highest yielding varieties are not very erect and early. From personal communication of onion breeding companies (F. van de Crommert 2010) we can expect at least progress on the combination of downy mildew resistance and earliness in the near future.

The trials also showed that onion was susceptible to drought stress and suffered severely from yield loss, especially in 2003. De Melo (2003) showed that there is genetic variability in root traits and that modern onion varieties have a more shallow rooting system than older varieties. Both conventional and organic onion production would benefit from varieties with an improved root system to overcome abiotic stress.

Although storability has reached a certain level through breeding, for organic growers this level is not high enough for long term storage.

Our conclusion is that for organic farming systems traits such as storability, dormancy, earliness in combination with resistance to downy mildew and leaf blight, erectness and improved root system or improved association with mycorrhizas (Scholten et al. 2010) would need improvement by breeding. Such traits can in principle be added to a conventional breeding programme. It seems logic that soil related traits such as association with mycorrhizas or improved root system can better be selected in the target environment. However research is needed to give evidence for this suggestion.

Conclusions

Our research results lead to the overall conclusion that to obtain information on many important traits, organic growers would not need separate organically managed variety trials when conventionally fertilised trials would refrain not only from pesticide, fungicide and sprout inhibitor use, but also from herbicide use. However, this would require an adaptation of the management protocol in such a way that trials might no longer be representative for conventional farmers. In that case an additional low-external input trial or an organically managed trial would have to be added and this would increase costs, the main reason why there are no organic trials in the first place. Designing a non-organic trial without pest treatments and four replications, of which two are treated with herbicides and two are mechanically weeded, would be a possibility, but chances are too high that such a trial will be associated with a large interaction between variety effect and replication effect, thus reducing the statistical power of the trial. In addition to changes in the protocol for management, there is also a need to include leaf erectness and disease resistance to downy mildew and leaf blight in the testing protocol. We found differences between systems for important traits like plant earliness and bulb uniformity, but results might have been influenced by differences in plant density between systems. For the short term, the organic sector should be able to profit from a more conscious selection among existing or new varieties. In the long run, there is a need for more communication with breeders on specific variety characteristics such as storability, dormancy, earliness in combination with resistance to downy mildew and leaf blight, erectness and improved root system or association with mycorrhizas that can contribute to yield stability under low-input, organic growing conditions.

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