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Location of project:	University of Warwick
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a three-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

Current bulb planting practice of 17 t/ha at 15cm depth remains the overall recommendation although bulb density at planting can be increased to 27 t/ha where flower production is the priority.

Planting bulbs upright gives significantly better results in comparison to planting upside down, however, random orientation remains the most practical and economic approach.

Technology exists to improve pest and disease control in lifted bulbs but is not likely to be a cost effective investment in current market conditions.

Background

The UK narcissus industry lags behind other arable and horticultural sectors in terms of the technology it employs, despite leading the world in terms of its output. The heyday of narcissus research came in the 1950s to 1980s, mainly courtesy of the Rosewarne and Kirton research stations, when many of the agronomic parameters affecting yield and crop quality were established, as well as refinements in crop handling and pest and disease control. However, changes in production practices, markets and varieties have rendered much of the evidence and recommendations out of date and therefore, the findings of this period need to be examined, and if necessary revised, to reflect the current market and practices. Innovation and advances in production practices have been made in other industries, notably potatoes and onions, and it is hoped that some of these may be transferable to Narcissus production to address some of the problems facing the industry, or simply to boost productivity while lowering costs; a necessary intervention in a time when production costs are rising, but retailers are static on pricing.

Summary

This summary briefly describes three aspects of the research: grower audit, overseas innovations and field trials.

Grower audit

An audit of all UK Narcissus growers was undertaken between autumn 2013 and spring 2014. This served two purposes: firstly, to record current grower practices with a view to inform the development of the later research and, secondly, to act as a method of engagement with the industry. Thirty-one growers representing an estimated 88% of the UK daffodil area responded which was excellent and provided a robust overview of industry practices.

Variety

Growers were asked to report their top ten (or fewer) varieties by economic importance. The results show that the same varieties are preferred for both flower and bulb production with Carlton being the most popular by incidence (number of growers growing it) (Table 1). In fact, the same top five varieties are mostly the same for flower and bulb production. The number of varieties grown by individual growers varies considerably with some using up to fifty varieties to cover the full range of season and markets while others make do with just four.

Table 1. Variety preference by intended use. All regions and growers.

Number	Flower production		Bulb production	
	Variety	**Incidence**	**Variety**	**Incidence**
1	**Carlton**	**22**	**Carlton**	**15**
2	Golden Ducat	18	Dutch Master	13
3	Standard Value	17	Golden Ducat	12
4	Dutch Master	15	Golden Harvest	9
5	Tamara	14	Tamara	9
6	Golden Harvest	12	Ice Follies	9
7	Mando	11	Standard Value	9
8	Ice Follies	9	Dellan	7
9	Dellan	8	Mando	7
10	California	8	Red Devon	6
11	St Keverne	6	White Lion	6
12	Sempre Avanti	5	California	6
13	Emblyn	5	St Keverne	6
14	Jedna	5	Fortune	5
15	Lothario	4	Barenwyn	5
16	Barenwyn	4	Jedna	5
17	White Lion	3	Cheerfulness	4
18	Counsellor	3	Pink Pride	4
19	Grand Soleil D'or	3	Emblyn	4
20	Red Devon	2	Sempre Avanti	4

Cornish growers typically use yellow division-1 and -2 varieties for flower production with little concern for bulb sales. There is a small trade in division-8 varieties (scented, multi-headed tazettas).

The preference for different varieties does vary by area, though some are fairly universal. In conversation with the growers, it became clear that the discrepancy in the number and type of varieties grown was down to different market strategies. One grower estimated that a minimum of 16 varieties would be necessary to ensure a supply of cut flowers for the length of the season, plus another 16 as backup, should some flower unusually early or late. To this are added double varieties and *N. tazetta* hybrids for special interest sales. However, in contrast, one grower used just four varieties with the intention of supplying the peak sale season (between Mother's Day and Easter Sunday). Growers supplying bulb-only varieties must grow an even wider selection to be able to meet customer demand for specific varieties.

Table 2. Variety preference by location.

Number	Cornwall	Lincolnshire & Cambridgeshire.	Scotland
1	Tamara	Carlton	Carlton
2	California	Dellan	Golden Ducat
3	Golden Ducat	Fortune	Golden Harvest
4	Mando	Mando	Dutch Master
5	Carlton	Standard Value	Standard Value
6	Standard Value	Ice Follies	Ice Follies
7	Dutch Master	Tamara	Sempre Avanti
8	St. Keverne	Lothario	Red Devon
9	Jedna	Golden Ducat	Mount Hood
10	Dellan	Dutch Master	Pink Pride

Bulb sizes

Cornish growers sell mainly 10-12 and 12-14 cm grade bulbs, meaning they replant mostly the largest and smallest grades. Half of the growers reported discarding bulbs which were smaller than 8cm in diameter.

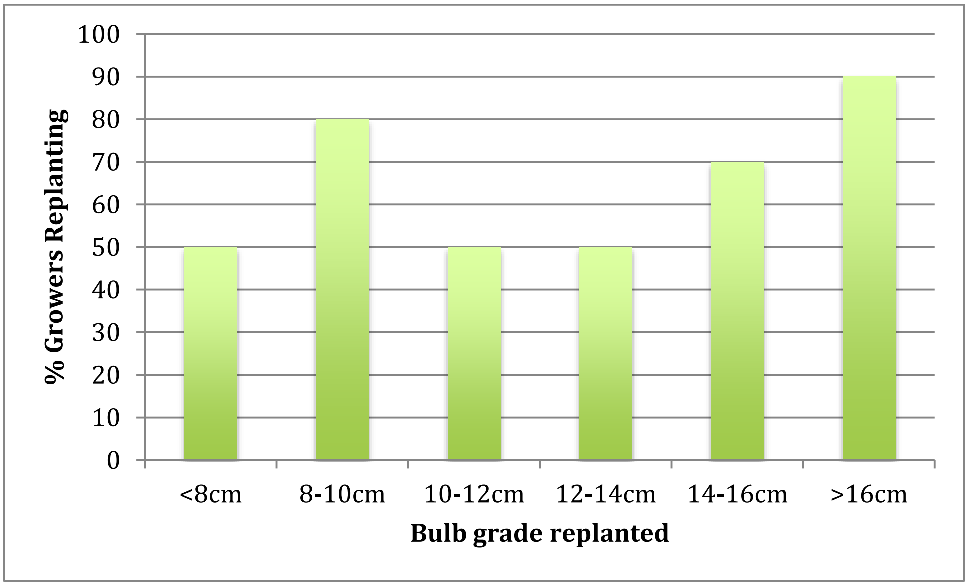

Figure 1. Bulb sizes replanted in Cornwall

Lincolnshire growers plant a more varied mixture of bulb grades, reflecting the variation in crop priorities (flowers or bulbs). One-quarter of them discarded bulbs smaller than 8cm in diameter.

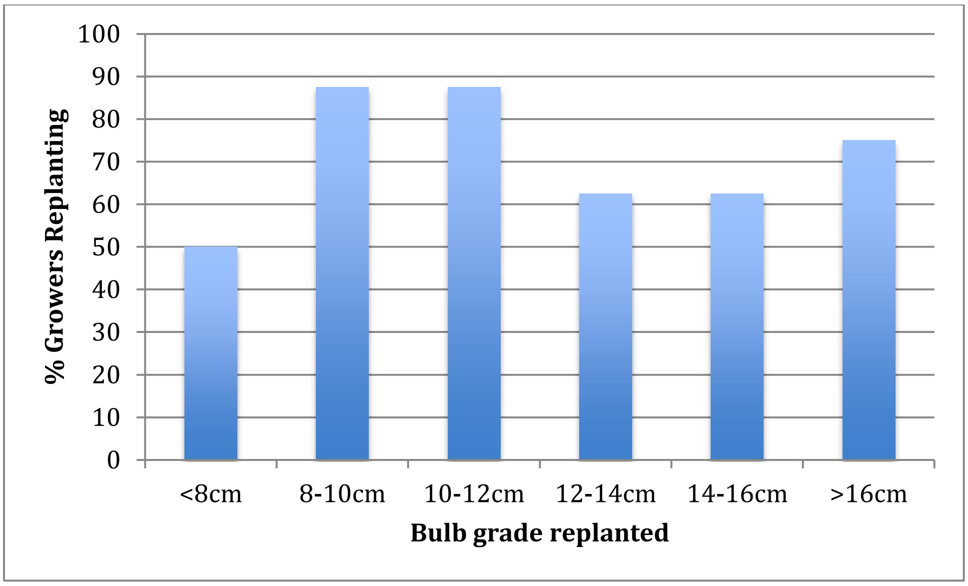

Figure 2. Bulb sizes replanted in Lincolnshire

Scottish growers are highly driven by bulb sales, so planting stock favors the smallest and largest grades. Only one grower discards bulbs smaller than 8cm in diameter.

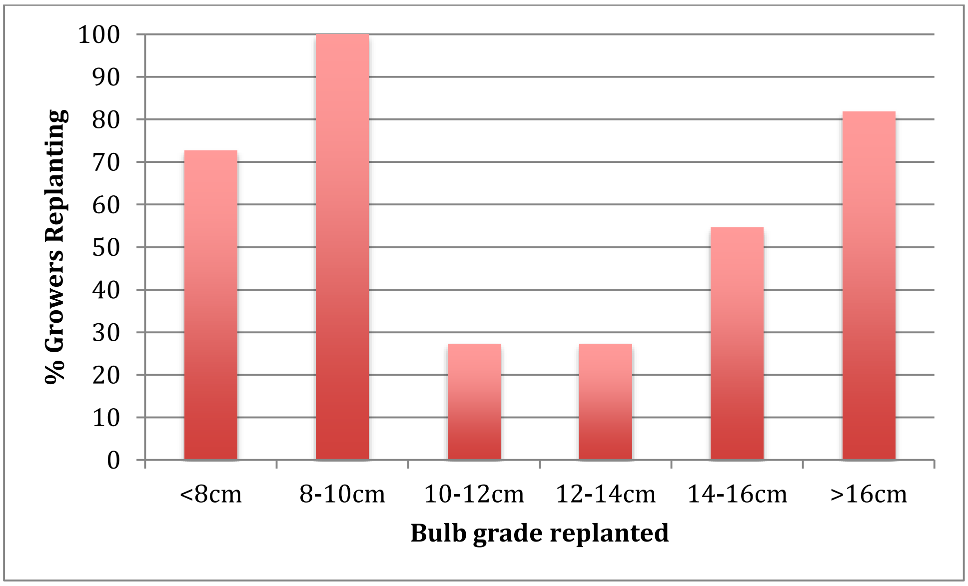

Figure 3. Bulb sizes replanted in Scotland

Hot-water Treatment (HWT)

Growers were asked to report on their HWT systems (front or top loading) and on the temperature used in HWT. They were also asked to indicate the choice or type of chemical additives used (fungicides, biocides/sterilants and adjuvants).

In Cornwall, bulbs are often pre-warmed at 30°C for one week before pre-soaking at 30°C and then HWT at between 46 and 47°C. Ambient-stored bulbs are treated at 44.4°C. Pre-warming (which subsequently allows higher HWT temperatures) reduces flower damage, allowing first year flowers to be harvested, which is the priority in Cornwall. Bulbs treated at the lower temperature are generally smaller grades that are not required to yield flowers in the subsequent growing season. Seven out of ten growers reported using front-loading HWT tanks, mostly holding eight boxes, while three use top-loading tanks, holding 2-3 bins each. HWT fungicide choice varied but an iodophore (an iodine based biocide), e.g. Fam 30, a wetter and acidifier are fairly consistent.

All growers in Lincolnshire and Cambridgeshire reported conducting HWT at 44.4°C. First year flowers are seldom harvested in the region, and so this temperature reflects the balance to be struck between flower yield and quality of bulbs, since the region exports more high-quality bulbs compared to Cornwall. Only two growers reported pre-warming, at 17 and 20°C respectively, where first year flowers were expected. There was an even split between top- and front-loading tanks.

In Scotland, Grampian Growers hot-water treats all of the bulbs for the growers in their co-operative. This is conducted at 47°C, following a 30°C pre-warm. The elevated treatment temperature is explained by the priority of the region which is bulb quality. The region frequently misses the peak flower market, but produces pest and disease-free bulbs for export overseas, especially for forcing in the Netherlands.

Research priorities

Growers were asked to identify their priority research needs. Cornish growers identified electronic screening of bulbs (8/10), followed by manual labour costs, energy costs, and the availability of land (7/10). In Lincolnshire, the priorities were different with growers identifying energy costs and manual labour as the most important (6/8), followed by drying efficiency (4/8). In Scotland, the cost of manual labour (11/11) and energy costs (10/11) were the most common. These results suggest that lowering input costs, especially energy, remains a priority while bulb quality, likely to be the incidence of rots, is important in Cornwall.

Overseas innovations

A visit was made to the Netherlands in August 2015 to tour their industry and to try and identify any innovations that might have application in the UK. The primary aim was to visit companies who specialise in equipment and technologies and to assess their function and suitability for

UK use, and to examine those which were in use by Dutch growers. The companies visited included: Akerboom, Sercom, Cremer and Warmerdam Spoelbedrijf. Visits were also made to bulb growers and the FloraHolland flower auction. Among the technologies viewed, the following took had perhaps the most promise for UK growers.

Foam disinfection cabinet: A recent introduction is the use of a foam based fungicide within the storage box to control Fusarium and other fungal diseases. Boxes are pressure filled with foam and allows to stand for 24 hours prior to use. If nematodes are not a problem, this looks like a quick and cheaper solution to HWT. However, anecdotal evidence suggests that with small bulb sizes, the foam may not penetrate the box and therefore some bulbs remain untreated. There is also some concern that bulbs may ‘clump’ together due to the sticky nature of the foam.

Controlled environment for pest control: This stores bulbs in controlled atmospheric conditions (ultra-low oxygen [1%] and high carbon dioxide [4%]) to kill nematodes inside the bulbs without damaging the bulbs themselves. This has mainly been used on lily and tulip bulbs but could easily be adapted for Narcissus. Timing would have to be examined to identify the optimum period but a combination of this and foam disinfectant would provide a ‘clean and low-chemical’ alterative to HWT, and reduce costs associated with disposing of large volumes of pesticide waste.

The visit demonstrated that Dutch growers are technologically advanced in comparison to most UK growers although that is likely to the result of supplying into a demanding high-value market rather than for any other reason. While many of the technologies they employ are unlikely to be applicable to the UK Narcissus industry, some show promise for either reducing production costs or improving the quality of bulb stocks.

Field trials

A series of field trials was established to examine the effect of bulb density at planting, bulb depth at planting, bulb orientation at planting, different potassium fertiliser treatments and irrigation; field trials were conducted on multiple varieties (Carlton, Dutch Master, Standard value, Golden Ducat, Ice Follies and Actaea) at different locations. The experimental design comprised one main site (Wellesbourne in Warwickshire) with three satellite sites situated on commercial holdings (Truro in Cornwall; Spalding in Lincolnshire; and Laurencekirk in Aberdeenshire).

Warwick Crop Centre in Wellesbourne, Warwickshire hosted the full range of treatments, while the satellite sites hosted selected treatments. Each treatment was replicated three times in a randomised complete block design. Fertilisation and crop protection on the satellite sites was administered by the growers in accordance with their own practices.

The yield and quality of flowers was assessed in spring 2015 and 2016 (not commercial sites). The bulbs were lifted in early summer 2016. The plot size was 1.5m long x 1.0 wide. All bulbs were lifted, allowed to dry naturally under-cover for a few days and then cleaned to remove any soil particles. A total plot weight was taken and the bulbs were then sorted by size.

First year flower harvest

Although first year flowers are not generally expected to be as good, or as reliable an indicator, as second or third year flowers, the results show some clear trends. The most robust results, both in terms of numbers and statistical significance, were provided by the orientation treatments. This is perhaps not unsurprising, since common sense would predict that planting bulbs the wrong way up would be detrimental to flower production. However, it is satisfying that common sense is backed up by the evidence. Across all three locations, orientating the bulbs upright at planting resulted in better outcomes in comparison to both inverting them and random orientation. The difference between upright and inversion was large, mostly statistically significant and compelling. There was less of a difference between upright and random orientation but upright planting still resulted in improved performance.

Density also provided some clear results. Planting at 22 t/ha or greater produced more stems that were generally both longer and heavier. This suggests that typical commercial density of 17 t/ha may not be optimal for flower production, particularly in Cornwall, and that planting density could be increased if flower production is prioritised. Depth provided less compelling evidence. The results suggest that 10cm can be detrimental to stem length but there is little difference between 15 and 20cm.

However, the results from year one flower harvests should be treated with some caution. Although the evidence for better performance for correct orientation and higher density is robust, year one harvests are more variable than the following years. However, even allowing for that fact, the results are promising since they are mostly consistent across the three locations.

Second year flower harvest

The second year flower harvest at Warwickshire was more consistent than the first with the most noticeable difference being the lack of short, spindly flowers produced from the sides of the bulbs; there was an abundance of these in year 1. The result was that second year data had slightly higher means and smaller variance compared to the first.

The results show that overall there were no significant differences between the treatments although some trends were apparent. In terms of planting orientation, there was little to choose between random and upright orientation but both produced significantly more stems compared to inverted planting. Planting at 10cm negatively impacted stem length in 'Dutch Master' although there was little difference between planting at 15cm and 20cm. The effect of planting density on stem length is difficult to interpret due to an unusual response at 22 t/ha but overall it's likely that planting density did not influence stem length.

Year two bulb harvest

All four locations provided different soil and climatic conditions and this is reflected in the variation in the results. Means for the harvest variables demonstrate that the same starting conditions resulted in very different outcomes (Table 3). The difference between the lowest and highest bulb weight was 23.2 t/ha and in effect the bulb yield in Scotland was double that of Cornwall with the sites in Warwickshire and Lincolnshire fitting in between. This huge difference is driven primarily by soil quality with bulb quality and environmental conditions being contributing factors. This division has long been recognised by growers but it is satisfying to see it represented in the results. The fertile soils present in Scotland and Lincolnshire provided a good environment for increasing bulb stocks, with rates of increase being 161% and 127% respectively, which is in complete contrast to the sites at Warwickshire and Cornwall where increases were far smaller. In terms of site performance for bulb production, Scotland provided the highest yields, followed by Lincolnshire, Warwickshire and Cornwall; however, a more pragmatic view is that Scotland and Lincolnshire performed well while Warwickshire and Cornwall were poor.

Table 3. Summary statistics for bulb harvest results by location.

Location	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Warwickshire	24	25.9	7.7	43
Scotland	24	46.7	28.4	161
Lincolnshire	22	39.5	21.4	127
Cornwall	16	23.5	5.2	29

Bulb depth at planting

The combined bulb harvest results from across all sites for the depth treatments are presented in Table 4. Despite the huge difference in bulb yield between the sites and the relatively poor performance at 15cm in Cornwall, there is a recognisable relationship between planting depth at harvest and bulb yield at two years. Bulb yield and the increases in yield increase with deeper planting. The gains are marginal, ranging between 5% and 17%, but are real and deeper planting, up to 20cm, can be recommended.

Table 4. Bulb harvest results for depth treatment across all four sites.

Depth	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
10	32	31.3	14.3	84
15	32	33.7	16.7	98
20	32	35.4	18.4	108

Bulb density at planting

The combined bulb harvest results from across all sites for the density treatments are presented in Table 5. The results are textbook in nature and mostly to expectation despite poor yield at 17 t/ha in Cornwall. Total bulb yield at harvest increased with planting density as did yield relative to the starting density.

Table 5. Bulb harvest results for density treatment across all four sites.

Planting Density (t/ha)	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
12	43	28.7	16.7	139
17	43	33.7	16.7	98
22	43	40.5	18.5	84
27	43	44.2	17.2	64

Bulb yield varied by region and was mostly a function of soil quality (Figure 4). The heavier moisture-retentive soils in Aberdeenshire and Lincolnshire significantly out-yielded the poorer quality soils at Warwickshire and in Cornwall. The largest increase, of approximately 250%, was observed when using a planting density of 12 t/ha in Lincolnshire, and the smallest, less than 50% and on one occasion negative, was observed using a planting density of 17 t/ha or greater in Cornwall. This result highlights the polarisation of the industry between flower and bulb producing areas.

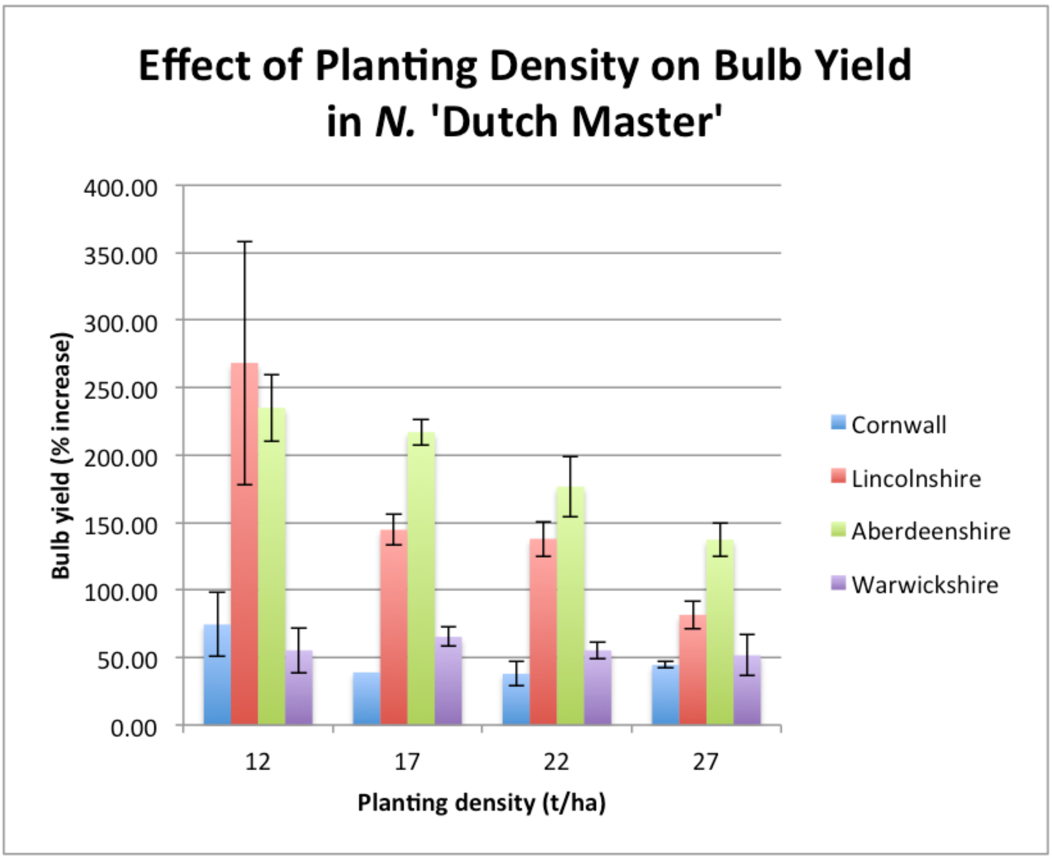

Figure 4. The effect of planting density on bulb yield

Bulb orientation at planting

The combined bulb harvest results from across all sites for the density treatments are presented in Table 4. The results are clear if not statistically significant; planting bulbs upright and with random orientation produces better yields and increases in yield. Field observations back this up. Inverted bulbs at harvest had either shorter twisted stems or in many cases, the stem had failed to reach the soil surface.

Table 4. Bulb harvest results for orientation treatment across all four sites.

Orientation	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Upright	32	33.8	16.8	99
Random	32	33.7	16.7	98
Inverted	32	29.2	12.2	72
All sites, all three orientations; p=		0.511	-	0.511
All sites, upright and inverted; p=		0.284	0.284	0.284

Summary of field trials

The trial design involved multiple replicated treatments across four sites in Warwickshire, Cornwall, Lincolnshire and Scotland. The trial was based on two flower harvests, spring 2015 and spring 2016, and a final bulb harvest in early summer 2016. Unfortunately, some data was not collected (the spring 2015 flower harvest in Lincolnshire and all the commercials flower harvests in spring 2016). This obviously detracts from the results and the conclusions and recommendations that follow. While the data used is robust, it is incomplete, and this should be borne in mind when taking decisions based on the contents of this report. This is of greater concern for flower production than it is for bulb production where the full dataset was available.

Three planting depths were examined: 10, 15 and 20cm. Planting depth did affect first year flower production with the best results found at 15cm and 20cm. Planting depth was also a factor in bulb yield with the best results again at 15cm and 20cm.

Four densities were examined: 12, 17, 22 and 27 t/ha. Planting at 22 and 27 t/ha produced the most flowers with the heaviest stems which suggests that where flower production is the priority, the typical planting density of 17 t/ha could be increased. Where multiplication of bulbs stocks is the priority, 17 t/ha at planting is probably optimal.

Three orientations at planting were examined: upright, random and inverted. Orientation had a profound and mostly significant effect on first year flower production with bulbs planted upright producing the most, longest and heaviest stems. Upright produced a small advantage in comparison to random planting and a large advantage in comparison to inverted planting. This advantage was carried through to bulb yield.

These trials assumed that typical grower practice is to plant bulbs at a depth of 15cm, a density of 17 t/ha and using random orientation. The results show that this approach provides perfectly acceptable results across both flower and bulb production as shallower planting and reduced bulb density are likely to depress yield. However, the results also show that slightly deeper planting at higher densities will benefit flower production in particular and for those growers who target flower production rather than bulb production, this would seem to be advantageous.

Bulb orientation at planting is different as it is very rarely under a grower's control. Typical practice is to tumble bulbs into rows and orientation at planting is therefore random. The results show that this is an area where innovation, if possible, would pay dividends. Upright planting, unsurprisingly, always offers an advantage in comparison to random or inverted orientation. The difficultly is achieving it, as currently no machinery or technology is in commercial production to deliver this outcome.

In many respects, these results are not new but they are a confirmation of existing grower practices. As the Narcissus industry becomes further polarised into bulb and flower production, rather than a combination of both, they do offer growers some evidence on which to change their practices to focus on one or the other.

Action Points

- In-box post-HWT fungicidal foam appears to be a promising innovation that might replace, or supplement, the use of fungicides in HWT. It is recommended to carry out a comparison of approaches to compare the efficacy of different approaches and products.
- The use of controlled atmospheric storage to control pests (nematodes, mites and bulb fly) should be investigated. Reduced oxygen conditions might provide a clean and dry alternative to HWT.

SCIENCE SECTION

Background

The UK Narcissus industry lags behind other arable sectors in terms of the technology it employs, despite leading the world in terms of its output. The heyday of Narcissus research and development came in the 1950s-1980s, mainly courtesy of the Rosewarne and Kirton research stations, when many of the agronomic parameters affecting yield and crop quality were established, as well as refinements in crop handling and pest and disease control. Since that period, an increasing demand for flowers, a decreasing demand for bulbs and a more competitive market environment has challenged many of the traditional approaches.

The broad aim of this project is to examine current agronomic practices, to assess if they remain relevant, and if not, whether changes are required to reflect changes in equipment, production practices, markets, varieties and the changing climate. It is expected that precision solutions will be able to solve some of the problems facing the industry, or simply boost productivity while lowering costs; a necessary intervention in a time when production costs are rising, but retailers are static on pricing. Work within the project work is divided into six main objectives:

1. Review and explore the limitations of existing planting and fertilizing systems on crop production

A review was undertaken of the academic literature, principally bulb, flower and potato production to understand and chart the development of bulb conditioning, planting and fertilizing techniques. The review was supported by visiting (or perhaps by telephone interview with growers in the United States) growers in the UK and the Netherlands to understand the drivers and limitations that apply to flower production. The purpose of this objective was to provide the necessary background required for the overall project and to build relationships with growers who might be able to assist with the practical work in the later objectives. Collaboration with the HDC Bulbs and Outdoor Flowers Panel and The Cut Flower Centre identified UK growers (from Cornwall, Lincolnshire and Scotland) who were prepared to assist with the project. This objective addressed both the academic requirement of the studentship and the more applied approach that will benefit growers in the long term.

2. To examine post-HWT bulb drying

Growers routinely dry newly-lifted bulbs using heated air to dry the bulb skin – improving durability and market appeal. Bulbs may also be pre-warmed prior to HWT to lessen the shock that the bulbs receive during HWT. Consequently, growers have drying walls operating at elevated temperatures. However, immediately after HWT, bulbs should be dried under ambient air to control the time the bulbs experience elevated temperatures. Little scientific evidence exists on the consequences if bulbs should be accidentally left against a heated drying wall or left with residual heat in storage boxes. Equally, how post-HWT drying influences bulb condition and ultimately flower yield is unexplored. Laboratory experiments will be undertaken using a number (and combination) of different treatments to examine how bulb conditioning influences bulb quality (prior to replanting) and flower yield and quality. The treatments will include various post HWT drying regimes (various times and temperatures including forced and ambient). All bulbs were replanted at Warwick Crop Centre in Warwickshire, Warwickshire to assess flower yield and quality in the first (and second) years following re-planting.

3. To examine the influence of planting on flower yield and quality

A multi-variety and treatment field trial was established at Warwick Crop Centre to examine how bulb variety, conditioning treatment, spacing, depth and orientation affect flower yield and quality. Treatment design was based on current best practice from the three principal UK growing areas and European and American production. Different climate conditions were simulated using covers and irrigation. Two-year field trials were established at four UK sites in Aberdeenshire, Cornwall, Lincolnshire and Warwickshire.

Existing agronomic practice and reluctance to change can mask the benefits that can accrue from new technologies and agronomic approaches. To overcome this issue, a modelling approach was used to simulate a number of different production systems to identify some optimum approaches. A database of planting information (row/bed, bulb grade, planting depth, bulb and row spacing, effect of bulb orientation, fertiliser rates and application type) was collated and multi parameter modelling techniques were used to assess optimum practices regardless of current practices.

4. Modify existing, or develop new, approaches to bulb planting and precision application of fertilizers

The key to precision is new technology (mechanical, electrical and computing) and the ability and training to implement it in the field. This studentship addressed the first part. Current bulb agronomy can be somewhat crude compared to the best available technology that is available in the bigger agricultural sectors. This part of the studentship examined the best precision farming techniques from the arable, potato and field vegetable sectors and assessed their transferability to bulb and flower production. Those which are considered the most promising were developed in collaboration with the industry to the point where they can be trialled in the field.

5. Undertake trials to assess the effectiveness of new approaches

Within a three year project, one two-year-down field experiment was possible. In the second year of the studentship, a field trial was undertaken at Warwick Crop Centre to assess the functionality and practicality of multiple approaches. These approaches included: current commercial practice, best practice as generated within objective two (planted and fertilised by hand), and two or three further approaches based on best available technology. Further field trials were held on grower's holdings to assess the suitability of new techniques in differing soil types and climates.

6. Develop best practice guidance for the use of new or innovative technologies

In consultation and collaboration with the commercial industry (growers and machinery manufacturers), the results from objective four will be developed into best practice guidance. This could take the form of advice on modifications or new ways of using existing machinery to instructions on the use of new or unfamiliar machinery or techniques. This advice and guidance will be collated into a technical bulletin.

General timeline

This report covers the period October 2013 to September 2016.

October 2013 to September 2014

The first year was devoted to gaining an understanding of the industry, so that investigations and field trials could be tailored to their standards and practices. An audit was conducted to collate evidence on industry practice regarding its growing year and the specific varieties, crop protection products and machinery employed. It also investigated which precision technologies the growers think will most benefit their production.

The audit did produce one interesting observation which was that bulb orientation at planting has no effect on subsequent growth as bulbs are said to right themselves when growing. Given the influence that this might wield on yield and quality, an experiment was designed to observe this, and to deduce the mechanism by which it occurs. Narcissus have been shown to have contractile roots capable of pulling the bulbs deeper into soil. The expectation (or hypothesis) was that bulbs planted sideways or fully inverted would use these roots or else deform the bulb to right the growing shoot.

In order to provide familiarisation with precision technology and techniques, visits were made to a number of agriculture events, e.g. CropTec in October 2013 and November 2014. These provided a wealth of information about existing precision technologies on the UK market, although they are mainly cereal- and brassica-centric. Soil nutrient mapping is a well-established practice (already indirectly employed by some growers). Yield mapping for potatoes has recently been developed and could be applied to Narcissus, though this only measures yield mass and not size grades. Crop canopy colour measurement (by aerial drones or surface probes) as a measure of overall crop health is already available for wheat and barley, and could easily be adapted to Narcissus.

October 2014 to September 2015

The second year was mainly devoted to planning and establishing field trials at four different locations; the main field site was at Warwick Crop Centre with satellite sites on grower's holdings in Cornwall, Lincolnshire and Aberdeenshire. Bulbs were planted during autumn 2014 and a first flower harvest was taken in spring 2015.

A study tour was made to the Netherlands to explore their production techniques and to try and identify any innovative approaches or equipment that could be used in the UK.

October 2015 to September 2016

The third year was dominated by a second flower harvest and the bulb harvest.

Grower audit

An online survey of growers was developed using SurveyMonkey™, and distributed via email to as many growers as possible, either by personal contact or through AHDB Horticulture. The survey asked questions about the scale of each company's operations, the principle varieties used, the bulb handling practices used and gauged growers' opinions on which problems they would most like solved and which precision technologies would be of most interest.

Response rate and grower holdings

Responses were received from 31 growers. It is estimated that this response rate accounts for 78% of UK growers and represents an area of 3,513ha of commercial holdings (c88% of UK area). The response rate was fairly complete for the Cornish and Scottish growers but fairly poor for the Lincolnshire area. In overall terms, the response rate is good and we are comfortable that the sample size is sufficiently large to provide robust results.

Growers were not obliged to answer all the questions, so the number of responses for each question varies. Growers were also able to add answers and extra comments of their own, to ensure the audit was not restrictive. These answers were tabulated with existing options where appropriate.

In terms of area, the industry is focused on Cornwall, particularly in and around Truro (Table 1). Cornish growers represent 77% of the overall area and comprises a range of different size holdings. The biggest grower, Greenyard Flowers, farms double the amount of daffodils as the second biggest grower, Rowe Farming, and on its own represents 30% of the total UK area.

Table 1. Grower's daffodil holding in Cornwall.

Grower	**Area (ha)**
Greenyard Flowers UK (Winchester Growers)	1,153
Rowe Farming	600
Maurice Crouch	350
R.H. Scrimshaw & Sons	140
J.H. Richards & Sons	120
Cornish Bulb Growers Ltd	80
[Unnamed]	80
Fentongollan	70
R. E. Body	64
JJ & AS Combe	40
TOTAL	**2,697**

Gowers in Cambridgeshire, Lincolnshire and Norfolk represent 12% of the total area and in general terms tend to be smaller compared to their Cornish contemporaries Table 2). This probably reflects both the competition for land in this area and the dual nature of their output which tends to be split between flower and bulb production.

Gowers in Angus, Aberdeenshire and Kincardineshire represent 11% of the total area (Table 3). Production is generally geared towards bulb production although flowers can make an economic contribution to the farming business in some years.

Table 2. Grower's daffodil holdings in Lincolnshire, Norfolk and Cambridgeshire

Grower	Area (ha)
O.A. Taylor & Sons	140
Jack Buck	100
P.S. & J.E. Ward	52
T.H. Charlton & Sons	36
K.W. Naylor & Son	35
J. Fowler & Sons	25
Hay Farming	16
N. & D. Bacon	14
L & D Flowers	5
TOTAL	**423**

Table 3. Grower's daffodil holdings in Angus, Aberdeenshire and Kincardineshire

Grower	Area (ha)
Inch Farming Co	64
N. J. McWilliam & Co	60
J. I. Forbes	48
D.M. Cargill	35
Reidhall Farms	32
A. J. Lyburn	30
R. & N. Cessford	30
R. M. FORBES & PARTNER	30
Messrs I. D. Salmon	26
G. M. Barclay & Sons	22
Dunbar Farmers	16
TOTAL	**393**

The results reveal many orders of magnitude in the scale of production between growers, ranging from over 1,100 ha down to just 2 ha for one grower for whom daffodils are a minor crop. Cornwall presents the largest variation in grower size, while the growers of the Grampian co-operative in Scotland are small, but much more uniform in size.

Variety

Growers were asked to report their top ten (or fewer) varieties by economic importance. The survey asked for at least one early, middle and late variety.

The results show that the same varieties are preferred for both flower and bulb production with Carlton being the most popular by incidence (number of growers growing it) (Table 4). In fact, the same top five varieties are mostly the same for flower and bulb production. The number of varieties grown by individual growers varies considerably with some using up to fifty varieties to cover the full range of season and markets while others make do with just four.

'Standard Value' was the most universal late variety across all three regions. Similarly, 'Golden Ducat' is the double variety of choice in all three regions. Early varieties were more complicated, with 'Tamara' the outright favourite variety in Cornwall, and popular in The Fens, but not grown at all in Scotland. 'Dutch Master' was ultimately selected as a compromise, bringing the added benefit of a wealth of existing literature for the variety. Mid-season varieties were least cohesive, with growers planting a wide and variable selection. 'Carlton' was ultimately selected, which despite waning popularity was relatively common and still makes up a large proportion of many farm stocks for historical reasons. 'Carlton' also has a large volume of previous research behind it.

'Ice Follies' was selected as a ubiquitous variety driven by bulb sales (including in mixtures), and 'Actaea' was selected to test the claim that different varieties require different agronomy – division 9 narcissus said to require lower growing densities. Although growers were given the option to name varieties not on the list provided, this did not throw up any widely popular choices.

One grower explained that a minimum of around 16 varieties is needed for continuous, season-long flower production, with another 16 required as backup. The audit revealed most growers do grow a wide selection (although they were only asked to name a maximum of 10). Only one large-scale grower seems to defy this, growing just four varieties.

Table 4. Variety preference by intended use. All regions and growers.

Number	Flower production		Bulb production	
	Variety	Incidence	Variety	Incidence
1	Carlton	22	Carlton	15
2	Golden Ducat	18	Dutch Master	13
3	Standard Value	17	Golden Ducat	12
4	Dutch Master	15	Golden Harvest	9
5	Tamara	14	Tamara	9
6	Golden Harvest	12	Ice Follies	9
7	Mando	11	Standard Value	9
8	Ice Follies	9	Dellan	7
9	Dellan	8	Mando	7
10	California	8	Red Devon	6
11	St Keverne	6	White Lion	6
12	Sempre Avanti	5	California	6
13	Emblyn	5	St Keverne	6
14	Jedna	5	Fortune	5
15	Lothario	4	Barenwyn	5
16	Barenwyn	4	Jedna	5
17	White Lion	3	Cheerfulness	4
18	Counsellor	3	Pink Pride	4
19	Grand Soleil D’or	3	Emblyn	4
20	Red Devon	2	Sempre Avanti	4

Cornish growers typically use yellow division-1 and -2 varieties for flower production with little concern for bulb sales. There is a small trade in division-8 varieties (scented, multi-headed tazettas).

The preference for different varieties does vary by area, though some are fairly universal. In conversation with the growers, it became clear that the discrepancy in the number and type of varieties grown was down to different market strategies. One grower estimated that a minimum of 16 varieties would be necessary to ensure a supply of cut flowers for the length of the season, plus another 16 as backup, should some flower unusually early or late. To this are added double varieties and *N. tazetta* hybrids for special interest sales. Conversely, one grower admitted to growing just four varieties with the intention of supplying the peak sales season between Mother’s Day and Easter Sunday. Growers supplying bulb-only varieties must grow an even wider selection to be able to meet customer demand for specific varieties.

Table 5. Variety preference by location.

Number	Cornwall	Lincolnshire & Cambridgeshire	Scotland
1	Tamara	Carlton	Carlton
2	California	Dellan	Golden Ducat
3	Golden Ducat	Fortune	Golden Harvest
4	Mando	Mando	Dutch Master
5	Carlton	Standard Value	Standard Value
6	Standard Value	Ice Follies	Ice Follies
7	Dutch Master	Tamara	Sempre Avanti
8	St. Keverne	Lothario	Red Devon
9	Jedna	Golden Ducat	Mount Hood
10	Dellan	Dutch Master	Pink Pride

Bulb sizes

Cornish growers sell mainly 10-12 and 12-14 cm grade bulbs, meaning they replant mostly the largest and smallest grades. Half of the growers reported discarding bulbs which were smaller than 8cm in diameter.

Lincolnshire growers plant a more varied mixture of bulb grades, reflecting the variation in crop priorities (flowers or bulbs) (Figure 2). One-quarter of them discarded bulbs smaller than 8cm in diameter.

Scottish growers are highly driven by bulb sales, so planting stock favors the smallest and largest grades (Figure 3). Only one grower discards bulbs smaller than 8cm in diameter.

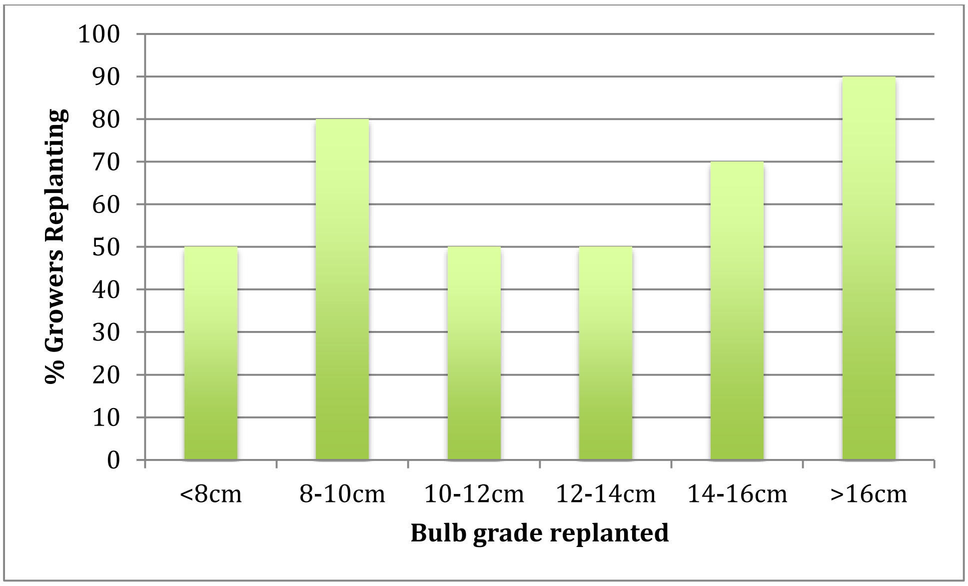

Figure 1. Bulb sizes replanted in Cornwall

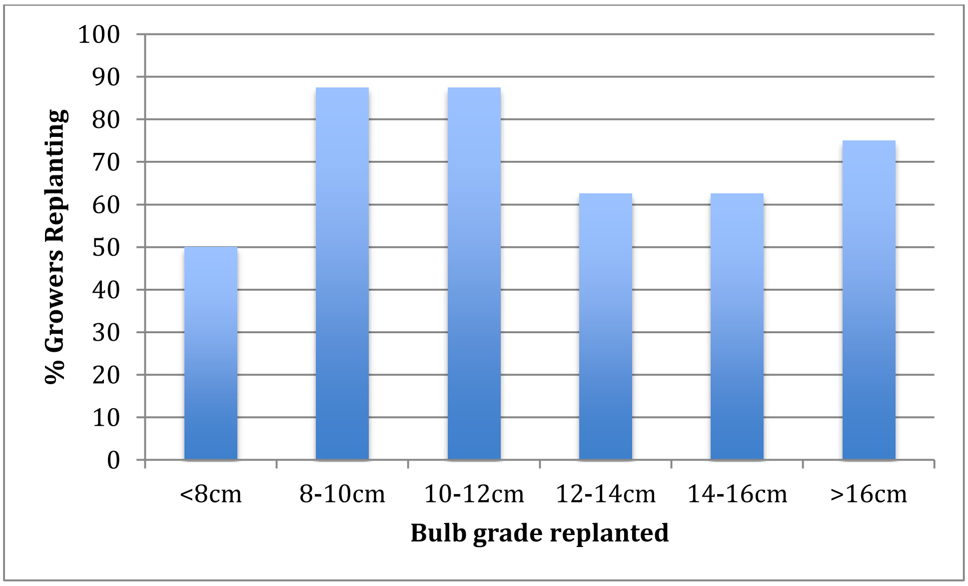

Figure 2. Bulb sizes replanted in Lincolnshire

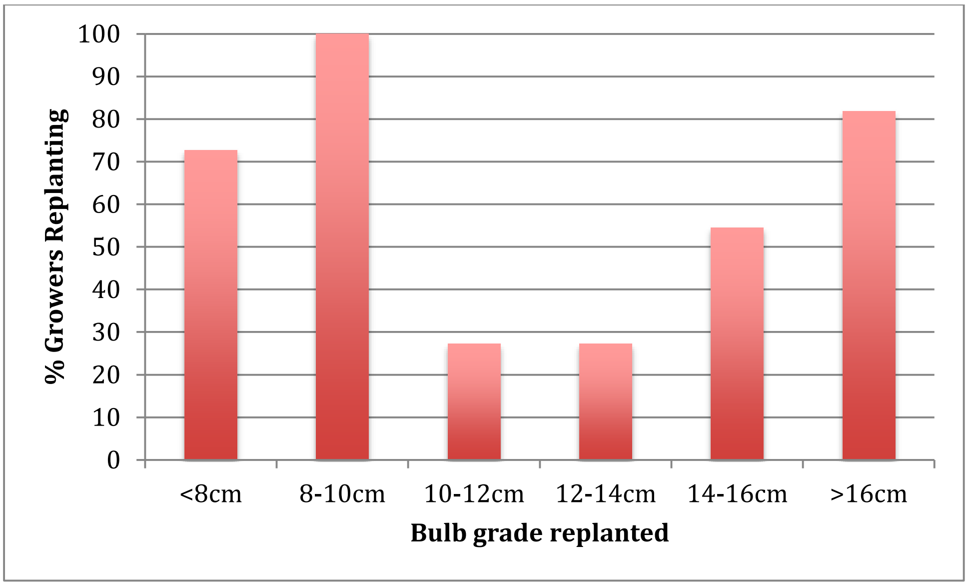

Figure 3. Bulb sizes replanted in Scotland

Windrowing as an initial drying method for lifted bulbs is used (weather permitting) in Cornwall and Grampian, but rarely in the Fens, where the soil is seldom dry enough. All twenty-seven respondents reported using a wooden bin system for drying after lifting, while nine also reported using a drying floor.

Hot-water Treatment (HWT)

Growers were asked to report on their HWT systems (front or top loading) and on the temperature used in HWT. They were also asked to indicate the choice or type of chemical additives used (fungicides, biocides/sterilants and adjuvants).

In Cornwall, bulbs are often pre-warmed at 30°C for one week before pre-soaking at 30°C and then HWT at between 46 and 47°C. Ambient-stored bulbs are treated at 44.4°C. Pre-warming (which subsequently requires higher HWT temperatures) reduces flower damage, allowing first year flowers to be harvested, which is the priority in Cornwall. Bulbs treated at the lower temperature are generally smaller grades that are not required to yield flowers in the subsequent growing season. Seven out of ten growers reported using front-loading HWT tanks, mostly holding 8 boxes, while three use top-loading tanks, holding 2-3 bins each. HWT fungicide choice varies, but an iodophore (e.g. Fam 30), a wetter and acidifier are fairly consistent.

All growers in Lincolnshire and Cambridgeshire reported conducting HWT at 44.4°C. First year flowers are seldom harvested in the region, and so this temperature reflects the balance to be struck between flower yield and quality of bulbs, since the region exports more high-quality bulbs compared to Cornwall. Only two growers reported pre-warming at 17 and 20°C, where first year flowers may be required. There was an even split between top- and front-loading tanks.

Grampian Growers hot-water treats all of the bulbs for the growers in the co-operative. It conducts this at 47°C, following a 30°C pre-warm. The elevated treatment temperature is explained by the priority of the region – bulb quality. The region frequently misses the peak flower market, but produces pest- and disease-free bulbs for export overseas, especially for forcing in the Netherlands.

Other agronomy

The audit revealed general agreement on some variables, such as the typical planting depth (c15 cm to the base of the bulb) and some aspects of bulb handling, such as drying times and temperatures. There was notable variation between growing regions in terms of the mixture of varieties planted, HWT temperatures used, bulb grades to be sold or planted and the overall business model in terms of focus on flowers or bulbs.

Planting depth did vary, with growers expressing answers differently, but overall, two rough camps emerged, one planting 15cm (6") and one planting 20cm (8"), expressed as depth to the base of the bulb. Shallower planting is more common in Cornwall, where soil is shallow and too stony to plough deeply. Most growers (22 out of 27) said they regularly conduct soil nutrient analyses before planting, although many do this for other crops in their rotation.

Primary industry concerns are control of basal rot, precision planting in terms of distribution of bulbs, efficient drying of bulbs and separation of clods and stones. Fertiliser placement is of interest in Cornwall, but considered less important elsewhere.

Research priorities

Growers were asked to identify their priority research needs. Cornish growers identified electronic screening of bulbs (8/10), followed by manual labour costs, energy costs, and the availability of land (7/10). In Lincolnshire, the priorities were different with growers identifying energy costs and manual labour as the most important (6/8), followed by drying efficiency (4/8). In Scotland, the cost of manual labour (11/11) and energy costs (10/11) were the most common. These results suggest that lowering input costs, especially energy, remains a priority while bulb quality, likely to be the incidence of rots, is important in Cornwall.

Observations of Self-righting and Depth Adjustment in Narcissus Bulbs

Glass-fronted plant growth tanks ('rhizotrons') were filled with Erin brand topsoil (compost and loam mixture) to a depth of 45cm. Bulbs of Narcissus 'Barenwyn' and 'Recurvus' were sourced, and one bulb was planted on the surface of the growing medium in each rhizotron, upright, inverted or sideways. Another 10cm of topsoil was added to each tank and watered to saturation. After allowing the growing medium to settle, the starting level of the base of the bulb was marked on the glass with a grease pencil, along with the direction of the bulb neck. The rhizotrons were kept in a glasshouse at ambient temperatures and watered to saturation weekly. The experiment ran from 14 February to 14 April 2014. The roots were photographed weekly for nine weeks, and the bulbs were finally excavated and examined after washing.

Sections of planted ridges on commercial growers' holdings were excavated by trowel and brush to expose the bulbs. The bulbs were photographed and inspected to see what proportion had self-righted after six, 12 and 24 months in the field. Deliberately inverted bulbs were excavated after six and 24 months to examine for signs of self-righting.

Results

No evidence was observed of the bulbs self-righting, nor of contractile roots pulling the bulbs deeper into the growing medium (Figure 2). Inverted bulbs simply grew a shoot that curved round and headed upwards against gravity. Some sideways or inverted bulbs showed roots growing between the bulb scales or under the tunic and breaking out of the side of the bulb.

Bulbs (mislabelled variety) at a site in Lincolnshire (soil type: sandy) showed no evidence of self-righting six months after planting, whether planted randomly or inverted. Bulbs of N. 'Tamsyn' at the same site showed little or no evidence of self-righting after 12 months. Bulbs of *N.* 'Salome' in a site in Cornwall (soil type: stony clay) showed partial self-righting, though many bulbs were still incorrectly orientated. Bulbs (*N.* 'Carlton', 'Dutch Master') at Warwickshire (soil type: sandy loam) had failed to self-right after 2 years being planted inverted.

Some bulbs excavated from plots where bulbs were planted randomly or inverted showed leaves and stems which had failed to escape the soil entirely. In some cases, not a single shoot had been able to reach light – losing an entire season's growth. It was hoped that this would be reflected in the figures of the first year flower harvest – expressed in terms of flowers produced per bulb planted. However, no difference was detected

Discussion

Results from all experiments challenge the notion that bulbs are able to quickly self-right upon irregular planting – within weeks or months. The data collected suggests that approximately 2-3 years are necessary for bulbs planted sideways and longer for bulbs planted inverted. The observation that roots may grow through the bulb upon inverted planting may have implications for infection by soil pests and pathogens.

The audit results reveal little standardisation between growers and between growing regions. It was originally hoped that this project would establish a growing model for all growers to follow. It will prove a challenge to make advice and recommendations that would be universally adopted, given the differences between flower- and bulb-focused production, and the massive disparity between the scales of operation. It seems likely that this project may introduce *more* variation (in the short term, at least) – some growers will be able to implement new practices sooner than others. This is influenced by expiration of growers' current setups (it does not usually make good business sense to replace an already new system or machine), economic circumstances (rising fertiliser costs are more likely to affect large growers sooner than small ones) and geographical limitations (irrigation might never be beneficial to growers in the Fens, where the water table is usually close to the surface) amongst other factors. Ultimately, however, this project should yield information which is universally applicable for narcissus production in any growing situation.

Figure 4. Clockwise from top left: Upright bulb with normal root and shoot orientation; sideways bulb showing bent shoot; inverted bulb showing 180˚ curved shoot; inverted bulb showing affected shoots; root growth from between scales; trapped roots beneath tunic.

Figure 5. Bulbs excavated on growers' land. Top row: Lincolnshire. Bottom row: Cornwall. Scale 50cm/10cm

Study tour to the Netherlands

Introduction

A visit to the bulb growing regions of the Netherlands took place in late August 2015. The primary aim of the visit was to meet with companies who specialise in equipment and technologies which might be useful to UK narcissus growers; and to investigate the suitability of those technologies, and to see which are already being used by Dutch growers. It became clear that Dutch growers are extremely advanced technologically, which fits with the demanding market for high-value products. While many of the technologies are unlikely to be applicable to the UK narcissus industry, some show promise for either reducing production costs or improving the quality of bulb stocks.

Jos Smit acted as a guide for the visit, being a useful go-between who is well-known by a wide number of ornamental crop growers and agricultural engineers. He works for three companies: Jac. Uittenbogaard & Zonen BV (JUB Holland)[1]; Green In Between; and Village Sensation.

JUB Holland is a bulb retailer, dealing in mainly domestic (Netherlands) grown bulbs, producing retail packs and displays for home consumer sales in many European countries. They also deal in bulk bulb orders to landscapers and produce their own mixtures for landscape planting. They provide a landscape planting service for municipal spaces, private residences and tourist attractions. Perhaps of most interest is their machine capable of planting bulbs underneath turf with minimal disturbance. This is a tool worth noting, less for industrial applications, but as something that may be of use for experimental purposes.

Green In Between is Smit's own bulb broking company, mediating grower-to-grower sales of industrial quantities of bulbs. This primarily involves importing bulbs from the UK for forcing or bulking up for retail. This is discussed in detail later.

Village Sensation supplies and maintains municipal displays of bedding plants, and is unlikely to be relevant to this project.

[1] https://www.jubholland.nl/en/retail/home-en/

Dutch Model of Narcissus Industry

Field-grown cut daffodil flowers are virtually non-existent in the Netherlands. Growers primarily operate two production cycles:

- The purchase from the UK of small grades of bulbs (typically 8-10cm) which are planted in outdoor bed systems for one year, then sell bulked up (now mostly 10-12 and 12-14 grade) bulbs for public retail.
- The purchase from the UK of medium grades of bulbs (typically 10-12, ideally bulbs which will only throw one, good flower and no leafy side shoots) and force under glass for early-season flower sales. The spent bulbs are then either discarded or, if the variety is of higher value, field-grown for two years as above for sale to the public.

Figure 6. Bulbs arranged in forcing trays. These are left outside until needed

A typical Dutch grower may have 15ha of daffodil bulbs, planting small bulbs at 22t/ha (yielding 50-55t/ha after one year). The Dutch climate and bed-planting system produces higher yields compared to UK ridge-grown crops, and favours enlargement of bulbs, rather than multiplication (i.e. ridges produce more small bulb grades). Bulbs are planted more densely at the sides of the bed, where they can access more sunlight and soil. The warmth of the soil and limited rotation options do mean that Dutch-grown bulbs tend to suffer more from pest and disease problems, especially compared to Scottish bulbs. Bulbs are typically lifted in July and planted in September or October, later than most in the UK.

Field-grown cut daffodils sold in the Netherlands are exclusively from the UK, especially the four largest Cornish growers. The largest Dutch client is possibly the supermarket chain Albert Heijn, although daffodils are not considered to be as iconic as spring flowers as tulips are, and sales per capita are lower than the UK. They also enjoy a peak market around Easter, but are not missed as deeply if supplies are short as they are in the UK.

Figure 7. Tightly controlled bulb storage requires custom containment. These airtight hangars contain lily bulbs stored below freezing point.

Nematodes present a big problem to Dutch growers. The shallow soil acts to concentrate them at the depth of the bulbs. Flooding fields to kill nematodes by suffocation is common for fields in most parts of Holland (though unlikely to be applicable in the UK). Fields are surrounded by raised banks to contain water, which is transferred in or out from dykes by tractor-mounted pumps. Other approaches include storing bulbs in controlled atmospheric conditions (ultra-low oxygen [1%] and high carbon dioxide [4%]) to kill nematodes within bulbs with minimal damage to the bulbs. This is mainly used for lily and tulip bulbs. Narcissus bulbs to be re-planted (from forcing) will be hot water treated, but at higher temperatures than the UK (often 48°C for four hours). Flower damage is not a concern while nematode control is a top priority. Formalin is banned for use in HWT, except for cleaning tanks, and it is said that some growers exploit this loophole to treat bulbs with the banned biocide. None of the half-dozen or so tanks I observed seemed to be using formalin. Some bulb retailers also specify that bulbs must be pesticide-free, which must be accommodated.

Akerboom (Walter Wildöer)

Akerboom[2] manufactures a range of machinery used for ornamental bulbs, particularly HWT tanks. Many UK growers already use tanks made by Akerboom. My visit was used to showcase other bulk treatment systems for bulbs.

Akerboom products are manufactures from welded mild steel, then shot-blasted and galvanised with molten zinc and/or coated with a two-part epoxide-based anti-corrosion paint. Tanks have an expected life expectany of 10-15 years before refurbishment is needed. Heater/pump units tend to fail first, being unprotected from corrosion.

One relatively new product on offer is a shower cabinet capable of drenching boxes of bulbs with a chemical wash. A conveyor automatically moves boxes through the cabinet for a 15-minute wash and drain cycle, processing one or two boxes per cycle. Cabinets are bespoke, to suit the size of box used by the customer in question. While this has a higher throughput than some of the smaller HWT tanks in operation in the UK, it does not provide as thorough coverage of the bulbs by the manufacturer's own admission.

Akerboom Foam Disinfection Cabinet

Current UK practice for treatment of bulbs post-lifting to control fungal diseases is hot water treatment. However, this is a time-consuming and expensive process so any innovations are likely to be welcomed by growers.

Akerboom are a well-known Dutch company who manufacture a wide range of machinery for flower growing. One recent innovation is to use a foam-based fungicide within the storage box[3] to control Fusarium and other fungal diseases.

Before use, measured amounts of water and a foaming compound are added to a holding tank, while pesticide actives are added to a separate tank. Mechanical agitators automatically dissolve the contents of each tank. Boxes are loaded onto the end of a conveyor. This transfers the box under the filling head which fills the box with foam, shutting off automatically when the box is full. The conveyor is capable of holding the next box to be treated, meaning one forklift operator is capable of loading and unloading the machine. The whole cycle lasts approximately 4 minutes. After treatment, boxes must be allowed to stand against a drying wall for 24 hours before bulbs are planted or the box is used. When not in use, the loading

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[2] www.akerboom.nl/EN/IndexeEN.html
[3] www.akerboom.nl/EN/Machines/Disinfection/Foamdisinfectionmachine/Foamdisinfectionmachineindex.html

arm of the conveyor can be folded by forklift for compact storage. This technology has a number of advantages and disadvantages in comparison to HWT:

Advantages

- Fast turnover (potentially 45 boxes in 3 hours, versus 16 for larger HWT tanks)
- Foam continues to work in storage
- Active and foam are combined at the point of application, meaning
  - No cross-contamination between boxes
  - Precise, equal dosing with every box
  - Minimal pesticide waste to dispose
  - Active ingredient can be changed between boxes
- Foam capable of penetrating bulb tunic
- Foam dries to a sticky residue, trapping dust and fungal spores, reducing cross-contamination in storage

Disadvantages

- No heat to kill nematodes, narcissus fly
- Cannot be forced-air dried for 24 hours, for risk of blowing pesticide-laden foam everywhere
- Bulbs may stick together upon drying – creating problems for planting
- Coverage of bulbs is not 100% complete – spots may be missed where bulbs are touching
- Unlikely pesticides penetrate deep into bulb
- Slow drying time could potentially encourage *Fusarium*

Figure 8. Akerboom's box sterilising apparatus. Built to client specifications

Perhaps the most useful Akerboom technology on offer is a box sterilising apparatus, using water at 80°C to disinfect the surface of wooden bulb/potato storage boxes. A single box is loaded into a cradle by forklift and the device lowers the cradle into a cabinet, where the box is rotated and sprayed with hot water, before being returned to be unloaded. The cycle lasts just five minutes. The process is capable of inactivating plant viruses, as well as killing living pathogens, and is now common practice with Dutch lily growers. It is recommended that the sterilisation be conducted as often as possible, but is most feasibly conducted at times when boxes are empty and time is less tight (i.e. May and November for daffodils). While this technology does not fit the description of a precision technology, and is therefore outside the scope of this project, I believe it is of sufficient benefit to the UK narcissus industry to be worth mentioning here.

Figure 9. A Sercom sensor box in use in a commercial glasshouse

Sercom (Jan-Willem Lut)

Sercom[4] produces electronic systems and components for the horticultural sector. Of main interest to me were their systems for monitoring drying of bulbs. Temperature and humidity sensor boxes are employed to compare conditions inside and outside the drying sheds, and automatically adjust the mixture of recirculated and introduced air to maximise drying efficiency. It can also adjust the temperature and airflow to the same effect.

The company prides itself on the flexibility of its electronics. Systems are expandable to accommodate greater numbers of sensors, updates are usually installable without the need for new hardware, and new products are checked for forwards/backwards compatibility. This reduces the cost to the grower when they choose to modify their setup. Secom software also comes with its own operating system to ensure reliability, but is also compatible with current Microsoft operating systems.

If air is forced too quickly through boxed bulbs, drying is uneven, over-drying bulbs close to the input of air, while leaving bulbs still damp further into the box. Over-drying of some bulbs causes the outer layers to rapidly contract, crushing the bulb and creating infection points for disease. Leaving bulbs damp for too long also encourages growth of fungal pathogens (e.g. *Fusarium* and *Penicillium*). Sercom's technology might result in energy savings during drying by increasing efficiency, but these alone are unlikely to make the technology financially attractive to growers. For the purposes of this project, it would be easy to show whether a given grower's drying setup is resulting in uneven drying of this type, but being able to quantify detrimental effects on the crop and the financial impact that results is a difficult task.

[4] www.sercom.nl/home

Perhaps the greatest advantage to growers is the system's ability to mix air from different sources – not just recycled air and outdoor air, but also (potentially) air from a glasshouse that has been heated by the sun. Few narcissus growers have glasshouse space, but for those that do not, solar heating of air could be a low-energy drying solution. Many growers already use photovoltaic solar cells, but air-, or water-heating solar panels are rare. Without an intelligent system to balance heat input from various sources, solar panels are an impractical heat source – supplying a highly variable rate of heat and even acting to lose heat from a system in cold conditions. However, the greatest heat output of a solar panel usually coincides with daffodil growers' peak demand for energy – drying bulbs after lifting in June/July. Evaluating the cost-benefits of this technology can be a purely mathematical exercise, i.e. not requiring practical experimentation.

Sercom also manufactures gas analysers for detection and control of ethylene in stored crops, and oxygen levels in ultra-low oxygen storage. A similar company, Agrozone[5], provides the option of ozone doping of crops stored in controlled atmospheres for the control of mites.

Ultimately, Sercom's technologies are of greatest interest to growers who concentrate on the quality of bulbs for retail, and as such are likely to be attractive primarily to the Grampian Growers co-operative in Scotland. Bulb quality is perhaps poorest in Cornwall, and improving quality here may benefit the flower crop, but data that might demonstrate this is less tangible and is likely to require a lengthy trial spanning multiple growing cycles.

Cremer (Ron van den Burg)

Cremer[6] manufactures counting machines. The first of these was developed in 1949, specifically to count flower bulbs for consumer sales. Today, the company develops and manufactures counting machines for customers from a wide variety of industries, especially pharmaceuticals, confectionery, horticulture and home chemical products (e.g. dishwasher tablets).

[5] www.agrozone-international.com/www.agrozone-international.com/index.html
[6] www.cremer.com/

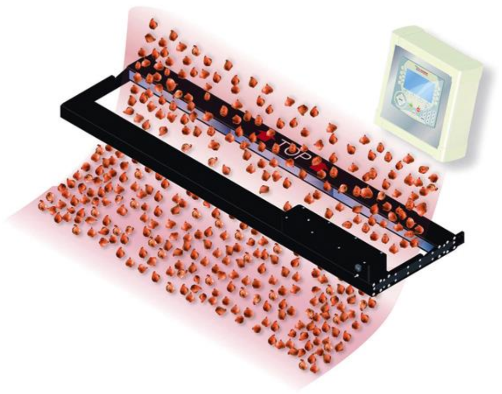

Figure 10. Cremer's Tel-O-Scope bulb counting system, already ubiquitous for tulips

Of prime interest was their Tel-O-Scope bulb counting systems, already used as standard by Dutch bulb growers. The device uses an array of infra-red LEDs opposite a bank of photodiodes. Bulbs fall through the gap in between, transiently reducing the intensity of light transmitted. The output of individual photodiodes is not measured, but rather the total voltage of the system. Software is able to interpret this variable signal to count the number of bulbs. My first concerns were that the machine may be unable to distinguish a loose bulb skin from a whole bulb, or count multi-nosed bulbs as multiple points, but demonstrations on a test rig indicated otherwise.

The count data is used to control the belt delivering the bulbs for planting. It adjusts the feed to meet a pre-set number of bulbs per metre of ridge. This can be altered while in operation, and automatically adjusts for the effects of roll and pitch as the tractor drives on sloping ground. The device dynamically accounts for dirt on the sensors and will flag up a warning if the sensor becomes too dirty to be accurate and can be quickly wiped clean. Jams and empty hoppers are also alerted.

The technology could be installed to UK-model ridge bulb planters. Although bulbs fall through in a single sheet, this can be split into two streams in a dividing chute as is already the case with ridge planters. The Tel-O-Scope cannot distinguish where individual bulbs are falling, and if a grower would like to control the count of bulbs going into each ridge, two entire, independent Tel-O-Scope counters would be needed, but this is unlikely to be necessary. The main mechanical obstacles to the technology are the facts that the counters come in standard widths and require a motor-driven belt and/or shaker plate to feed bulbs into the counter. Retro-fitting these to ridge planters could prove costly.

The cost of each Tel-O-Scope counter unit is approximately €10,000. According to Ron, on the Dutch market a 5% error in bulb density over 1 ha results in a €14,000 loss. It should be noted that this covers higher-value bulb crops and a different economy for bulb sales. The financial benefits to UK Narcissus growers should become clear in this project. What is potentially attractive is the reduction in labour needed for planting. Currently, a second operative is required to sit on the planter to adjust the flow of bulbs and to clear jams. Counting technology is capable of eliminating this need. If this worker is required for 200 hours at the current minimum wage of £6.70 per hour (for over-21's), this can be expected to save upwards of £1,000 per season per planter. The outdoor usage life of the Tel-O-Scope system is 10 years. This does put the cost-benefit ratio into some doubt, so the benefits of precise planting would need to be proven to make it viable.

Another bulb counting technology for use in packaging is available that counts individual bulbs in channels. Bulbs fall between electrically charged plates and the humidity around the bulb allows a detectable current to jump between the plates (which is not hazardous to human safety). Pneumatic 'memory flaps' are able to catch bulbs and release them to prevent over-counts falling into bags. Such a technology could, in theory, be fitted to planters and would provide much more precise distribution over a field, but is currently not ready for such use, and is expected to be more expensive than the optical system.

What cannot be ignored with these technologies is that they would require growers to shift from planting by bulb mass/area to number/area. This is not radical in itself, but provides a challenge to growers to adapt to a different method, accounting for effects of variety and bulb grade on the number of bulbs per tonne or per box. If there is a risk that yields may be erratic in early years while growers adapt to the changes, agronomic software (e.g. *Muddy Boots*) may prove useful in optimising a number/area planting method. Such software seldom has an automatic optimisation tool, but provides consultant agronomists with data in a standardised format that is quick to interpret.

Other Visits

Figure 11. *Hippeastrum* bulbs undergoing a wash and rinse to remove soil

Ruud Warmerdam runs a business washing and sterilising bulbs for grower clients (Warmerdam Spoelbedrijf[7]). This is usually to ensure they are of export quality, getting rid of soil, pests and diseases. A wide selection of treatments are on offer, from cold drenches to conventional, albeit small-scale HWT. Wash water is never recycled, to reduce cross-contamination, but is instead strained to remove solid waste, then collected in settling ponds for treatment and disposal. The experience was insightful into alternative bulb treatments which, while they may not fit the umbrella of 'precision agronomy', may prove useful to UK growers who value product quality, or are supplying to demanding customers.

I was able to visit various flower growers to see their stocks and operations. I observed temperature- and atmosphere-controlled storage of lily bulbs for year-round flower forcing, gained first-hand experience in identifying bulb disorders, including basal rot of tulips. I saw dahlia production, both for cut flowers and plant sales, including learning how the crop is mass-propagated. I was also able to visit a dahlia breeder and gain insight into the methods and organisation of selective breeding.

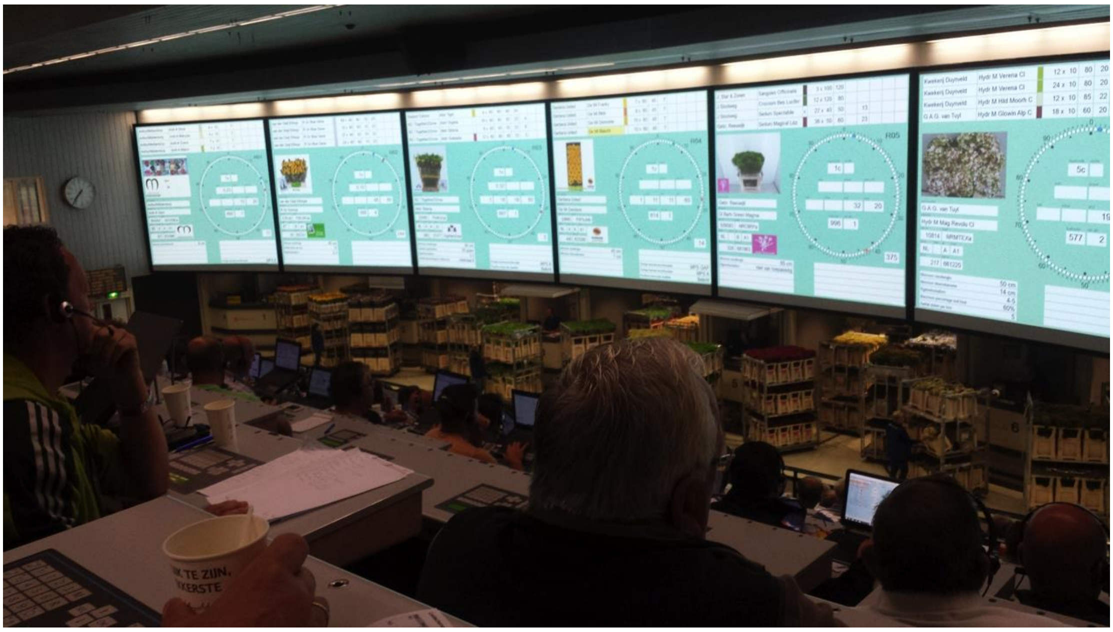

Figure 12. Auction room at FloraHolland, Rijnsburg. Capacity for around 200 buyers in the room and around 1000 nationally

[7] www.warmerdamspoelbedrijf.nl/

On the final morning of the trip, a visit was made to the FloraHolland[8] flower auction house at Rijnsburg. I was able to witness the bidding process for wholesale quantity flowers, which is entirely electronically governed, from auctioning to payment by Chip and PIN, and allows bidders to simultaneously bid on lots in the room and at other auction houses, via the internet. Details of the lots (quantity, quality, country of origin etc.) are displayed on large screens. Bidders select the quantity to order, at which point the price per stem starts counting down rapidly. The first bidder to interrupt the countdown by pressing a button at their desk buys their selected quantity. This cycle repeats until all the lot has been sold. Finally, I was introduced to some of the florists who operate from leased space within the auction house. The visit has helped me understand the supply chain for cut flowers and the demands of quality and price that are expected of growers.

Conclusions

Box sterilisers, while not classified as precision agronomy, would be a useful addition to growers' routines with immediate effect. They will help reduce cross-contamination and spread of basal rot, viruses, narcissus eelworm and potato cyst nematode, improving the health of the crop in the long term and improving the proportion approved for export.

Foam fungicide treatment and controlled atmosphere storage of bulbs should be tested in detail for efficacy in narcissus. If comparable to conventional HWT, they will have profound benefits in increasing throughput during bulb handling, reducing pesticide use and reducing costs associated with disposing pesticide waste. Both methods would be easy to test on small scales. Fungicide foaming machines are available to buy 'off-the-shelf', while controlled atmosphere storage requires greater investment.

Cremer's Tel-O-Scope planter-mounted counting system would reduce labour costs when planting bulbs. Growers would need to switch to a number-per-area model of growing bulbs. Since the technology is likely to be difficult to retro-fit to existing planters, implementation may be best reserved until an existing planter needs replacing entirely.

Sercom drying monitors are most suited to growers with bulb quality as high priority. At current energy prices the technology has few benefits to most growers, but may prove cost-effective in the future if combined with cheap sources of renewable energy.

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8 www.floraholland.com/en/

Innovations

Development of a computer model is underway to inform future Narcissus breeding programmes. The aim is to identify more distantly related pairs of parents and identify candidate varieties which contain desired traits and therefore widen the scope, in terms of the varieties, that are suitable for crossing. These actions will reduce inbreeding and allow for the production of more robust and vigorous progeny.

The program works by analysing existing data on historical crosses, breaking down the properties of the parents, based on official classification (e.g. 'Salome 2 W-PPY) and comparing both parents with the progeny to establish which traits are inherited. A prototype system has already identified that varieties such as 'Fortune' (2 Y-O) and 'Salome' (2 W-PPY) are potentially suitable for breeding all-yellow varieties. Previous breeding methods would likely have overlooked these candidate varieties.

The program tabulates existing pedigree data for known Narcissus varieties and identifies those with evolutionary relationships. Varieties are treated as nodes and the shortest paths between candidate varieties are found and compared. Progenitor species (e.g. *N. poeticus* and *N. triandrus*) are connected by extremely long paths, to reduce fragmentation.

Agronomic field trials

The largest component of the project was a series of replicated field trials. The design of these was informed by current grower practice (as revealed by the grower audit) and the requirement was to examine and update the results of agronomy trials conducted during the 1960 to 1980 period. The field trials focused on a number of important agronomic parameters, namely planting density, planting depth, bulb orientation at planting and crop nutrition.

Material and methods

This section describes the development and choice of treatments, and the varieties selected for the field trials.

Density

The audit revealed that the average planting density for flower production is approximately 17t/ha (of large bulbs), which is in agreement with the HDC Narcissus Manual (Hanks, 2013a). A density of 17t/ha for large bulbs should be expected to give a yield increase of about 170% after two years (Tompsett, 1974). For small bulbs, the audit gave an average planting density of 10t/ha. This should give a final yield increase of approximately 275% of planted weight.

Andrew Tompsett (personal correspondence) suggested experimenting up to very high tonnages, but this is not greatly supported by the growers and I believe that finer data for realistic tonnages is more worthwhile. His work at Rosewarne (Rees et al., 1973; Tompsett, 1970, 1974) has already provided some bulb yield data for very high tonnages, but has less data for lower densities.

The density treatments adopted for the trials were: 12, 17, 22 and 27 t/ha

Depth

The audit revealed that planting depth is fairly variable but 15cm to the base of the bulb is typical. This will be the control depth. Deeper planting is associated with taller stems and better bulb yields, but is more problematic to lift. Two other depths, 10cm and 20cm, will be used to provide a comparison. A factorial experiment between depth and planting density will be used for the variety 'Carlton'.

The depth treatments adopted for the trials were: 10, 15 and 20 cm.

Bulb Orientation

Bulbs, obviously, have a top and bottom. However, it is not yet possible to purchase planting equipment to orientate bulbs under commercial growing conditions, so grower practice is to tumble bulbs into a row so that orientation is random. This results in some bulbs being upright, some inverted and a majority lying on their sides. Previous work on bulb orientation did not provide any conclusive evidence of the outcome of this practice although it is assumed that the energy required to provide extra-long shoots and roots will have some detrimental effect on subsequent bulb and flower performance. Assessment of treatments affects will include flower timing, yield and quality, and also an examination of root and shoot architecture as this has implications for disease, particularly neck and basal rots.

Random orientation was created by simply dropping the bulbs in from a height of 0.5m – representative of current industrial planting. Orientated bulbs were similarly scattered, then turned upright or inverted by hand. Soil was backfilled against three depth gauges placed along the ridge and gently firmed until the required depth was achieved.

The orientation treatments adopted for the trials were: upright, random and inverted.

Covering

Results from the audit suggested that growers were not convinced of the usefulness and practicality of covering crops. However, protecting crops, for all or part of their growing period, has been shown to be beneficial in terms of yield and quality for other diverse crops, e.g. soft fruit, early or vulnerable vegetables and maize, so the effects of covering were investigated. Two treatments were implemented:

- Covering with fleece in winter until emergence in spring
- Covering with polythene immediately after planting until the start of winter

The former treatment was expected to promote early flowering while the latter was expected to delay flowering. While there is little commercial need for earlier flowers, growers have expressed a need for more late yellow varieties (personal correspondences), and since a commercial variety takes 20 years to breed and propagate, delaying the flowering of existing varieties may provide an appealing interim solution.

Unfortunately, both covering experiments were eventually discarded, due to unforeseen problems with disease, mislabelled bulb stocks and rogues.

Irrigation

Irrigation, except to soften the soil before lifting in very dry weather, is not used by any commercial growers. However, there is some evidence to suggest that daffodils respond to extra water with increased bulb yield when water, averaging 83mm per month, is supplied evenly across their growing cycle (Hanks, 2013b). To investigate this claim, one treatment received additional water as irrigation when fortnightly rainfall was less than 40mm, and soil moisture was low, between March and June (Hanks, 2013c). The major interest was to investigate the influence of water on bulb yield.

Fertiliser Placement

Bulbs in most experiments were fertilised with sulphate of potash (SOP) at a rate equivalent to 250kg/ha, with the soil harrowed before planting to evenly distribute the mineral in the soil. In a separate experiment, fertiliser was hand-placed in the ridges, covered with 25mm of soil and the bulbs planted. Fertiliser rates of 100%, 75%, 50% and 25% of the industry standard were used, with a no-fertiliser control and a hand-incorporated control to simulate broadcast fertiliser. Furthermore, a rate of 100% was applied in direct contact with the bulbs to establish any negative effects of such application.

Bulb varieties

Growers use multiple varieties to ensure a consistent supply of flowers during peak demand, which is typically mid to late January to mid-April. Growers may use as many as 20 varieties so selecting appropriate varieties for the field trials was a major challenge. Three broad categories were considered: early season, main season and late season; and from these the most popular varieties were identified:

- Carlton (C)
- Dutch Master (DM)
- Standard Value (SV)
- Golden Ducat (GD)
- Ice Follies (IF)
- Actaea (A)

Dutch Master bulbs were chosen as the control bulb and grown across all four sites. These were sourced from commercial growers in the same region, to reduce seasonal effects on the timing of the flowers (bulbs for Warwickshire came from Lincolnshire). Bulbs were planted into grower-made ridges. The other varieties were only grown at Warwickshire.

Trial location and treatment choice

To test the effect of multiple treatments on multiple varieties across different locations required a complicated experimental design. The overall design comprised one main site with three satellite sites situated on commercial holdings.

- Warwick Crop Centre, Wellesbourne, Warwickshire. The soil is a free draining slightly acid sandy loam with low fertility
- Truro, Cornwall. The soil is a lowly permeable seasonally wet acid loamy clay with low fertility
- Spalding, Lincolnshire. The soil is a silt loam with naturally high groundwater and fertility
- Laurencekirk, Aberdeenshire. The soil is a loamy clay with medium-high fertility.

Warwick Crop Centre hosted the full range of treatments, while the satellite sites hosted selected treatments. Each treatment was replicated three times in a randomised complete block design. Fertilisation and crop protection was administered by the grower in accordance with their own practices.

The yield and quality of flowers was assessed in spring 2015 and 2016. The bulbs were lifted in early summer 2016. The plot size was 1.5m long x 1.0 wide. All bulbs were lifted, allowed to dry naturally under-cover for a few days and then cleaned to remove any soil particles. A total plot weight was taken and the bulbs were then sorted by size.

Table 6. Treatments applied to field trials. All treatments were applied at Warwickshire but only treatments C, 1-5 & 12-13 were used on grower holdings

Treatment number	Planting depth (cm)	Large bulbs		Small bulbs		Orientation	Other treatment
		Density (t/ha	Varieties	Density (t/ha	Varieties		
C	15	17	C, GD, DM, SV	10	C, IF, A	Random	Control
1	10	17	C, GD, DM, SV	10	C, IF, A	Random	
2	20	17	C, GD, DM, SV	10	C, IF, A	Random	
3	15	12	C, GD, DM, SV	5	C, IF, A	Random	
4	15	22	C, GD, DM, SV	15	C, IF, A	Random	
5	15	27	C, GD, DM, SV	20	C, IF, A	Random	
6	10	12	C	5		Random	
7	10	22	C	15		Random	
8	10	27	C	20		Random	
9	20	12	C	5		Random	
10	20	22	C	15		Random	
11	20	27	C	20		Random	
12	10	17	C, DM, SV	10		Upright	
13	10	17	C, DM, SV	10		Inverted	
14	20	17	C, DM, SV	10		Upright	
15	20	17	C, DM, SV	10		Inverted	
16	15	17		10		Random	Cover - polythene
17	15	17		10		Random	Cover - fleece
18	15	17	C	10		Random	Ambient storage 1 day
19	15	17	C	10		Random	Ambient storage 7 days
20	15	17	C	10		Random	Ambient storage 28 days
21	15	17	C	10		Random	35 Celsius storage 1 day
22	15	17	C	10		Random	35 Celsius storage 7 days
23	15	17	C	10		Random	35 Celsius storage 28 days
24	15	17	C	10	C	Random	Irrigated
25	15	17	C	10	C	Random	Fertiliser Placed 100%
26	15	17	C	10	C	Random	Fertiliser Placed 75%
27	15	17	C	10	C	Random	Fertiliser Placed 50%
28	15	17	C	10	C	Random	Fertiliser Placed 25%
29	15	17	C	10	C	Random	No fertiliser
30	15	17	C	10	C	Random	Fertiliser Placed 100% in contact

Results

Flower harvest in spring 2015

Warwickshire - The flower harvest took place between the 16th March and 12th April 2015. Stems were harvested as they reached marketable stage of flower development, irrespective of length. Data was collected on the number of stems per plot, date of harvest, stem length and stem weight. A general quality assessment was made for

Table 7. Warwickshire flower harvest 2015. Main treatments for 'Dutch Master'.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Number of stems	Stem length (mm)	Stem weight (g)
Control	15	17	Random	26.3	273.8	8.1
1	10	17	Random	16.0	249.9	7.6
2	20	17	Random	21.0	265.0	8.1
3	15	12	Random	16.7	268.8	8.3
4	15	22	Random	37.7	265.4	8.2
5	15	27	Random	33.0	266.7	8.0
12	10	17	Upright	29.0	256.1	7.4
13	10	17	Inverted	1.3	240.1	7.1
14	20	17	Upright	37.7	254.7	7.9
15	20	17	Inverted	1.7	262.4	7.6
All treatments; p=				N/A	0.011	0.477
Depth (Treatments C, 1 & 2); p=					0.091	0.725
Density (Treatments C, 3, 4 & 5); p=					0.626	0.910
Orientation (Treatments 1, 2, 12, 13, 14 & 15); p=					0.382	0.297

The main treatments examined the influence of planting depth, planting density and bulb orientation on first year flower performance. Three planting depths were used: 10, 15 and 20cm. Planting at 15cm produced the highest number of stems and longest stem length while planting at 15 and 20cm produced the greatest stem weights although none of the differences across the three metrics were statistically significant. Four planting densities were examined: 12, 17, 22 and 27 t/ha. Planting at 22 and 27 t/ha produced the most flowers although there was little difference in either stem length or stem weight. Three orientations were examined: random, upright and inverted. Orientation had a significant effect on the number of stems produced. Upright orientation provided a statistically significant increase (p=0.007) compared to random planting; it doubled the number of stems. The difference between upright and inverted planting was huge with upright planting providing a twenty-three-fold increase in stem number compared to inverted bulbs.

The results show that an upright orientation and high (>22 t/ha) planting density had the greatest positive influence of the number of stems produced. Inverting bulbs, not unsurprisingly, had a severe negative effect on the number of stems produced, stem length and stem weight.

Scotland – The flower harvest took place on the 25th March 2015. Operational difficulties meant that only ten stems were harvested from each plot. Data was collected on the stem length and stem weight.

Table 8. Scotland flower harvest 2015. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Stem length (mm)	Stem weight (g)	
Control	15	17	Random	254.6	7.0	
1	10	17	Random	238.8	7.1	
2	20	17	Random	256.9	7.6	
3	15	12	Random	253.6	8.1	
4	15	22	Random	263.4	8.3	
5	15	27	Random	268.7	8.5	
12	15	17	Upright	261.3	8.2	
13	15	17	Inverted	236.2	7.4	
All treatments; p=				<.001	0.008	
Depth (Treatments C, 1 & 2); p=				0.053	0.494	
Density (Treatments C, 3, 4 & 5); p=				0.227	0.014	
Orientation (Treatments 1, 2, 12 & 13); p=				0.005	0.048	

The main treatments examined the influence of planting depth, planting density and bulb orientation on first year flower performance. Three planting depths were used: 10, 15 and 20cm. Depth did significantly affect stem length with shallow planting (10cm) producing the shortest stems. No difference was observed between planting at 15 and 20cm. Four planting densities were examined: 12, 17, 22 and 27 t/ha. Planting at 22 and 27 t/ha produced the longest stem lengths and highest stem weight. Three bulb orientations at planting were examined: random, upright and inverted. Orientation had a significant effect on both stem length and weight. Upright planting resulted in the longest and heaviest stems while inverting the bulbs at planting restricted stem length although not really stem weight.

The results show that an upright orientation and high (>22 t/ha) planting density had the greatest positive influence on stem length and weight. Inverting bulbs negatively affected stem length.

Cornwall – The flower harvest took place on the 3rd March 2015. Ten typical stems were harvested from each plot. Data was collected on the stem length and stem weight.

Table 9. Cornwall flower harvest 2015. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Stem length (mm)	Stem weight (g)	
Control	15	17	Random	261.2	8.3	
1	10	17	Random	262.5	8.5	
2	20	17	Random	262.9	9.0	
3	15	12	Random	271.6	8.2	
4	15	22	Random	262.3	8.3	
5	15	27	Random	294.2	10.4	
12	15	17	Upright	264.3	8.3	
13	15	17	Inverted	244.3	7.8	
All treatments; p=				<.001	<.001	
Depth (Treatments C, 1 & 2); p=				0.974	0.433	
Density (Treatments C, 3, 4 & 5); p=				0.004	0.001	
Orientation (Treatments 1, 2, 12 & 13); p=				0.149	0.610	

The main treatments examined the influence of planting depth, planting density and bulb orientation on first year flower performance. Three planting depths were used: 10, 15 and 20cm. Depth did not significantly affect stem length or stem weight with only minor differences between the treatments. Four planting densities were examined: 12, 17, 22 and 27 t/ha. Planting at 27 t/ha produced significantly longer and heavier stems in comparison to the other treatments. Three bulb orientations at planting were examined: random, upright and inverted. Orientation had a beneficial effect on both stem length and weight. Planting bulbs upright resulted in a significantly longer stem in comparison to inverted planting (but not random orientation) while stem weight was greater with both upright and random orientation in comparison to inverted planting.

Summary

Although first year flowers are not generally expected to be as good, or as reliable an indicator, as second or third year flowers, the results show some clear trends. The most robust results, both in terms of numbers and statistical significance, are provided by the orientation treatments. This is perhaps not unsurprising, since common sense would predict that planting bulbs the wrong way up would be detrimental to flower production. However, it is satisfying that common sense is backed up by the evidence. Across all three locations, orientating the bulbs upright at planting resulted in better outcomes in comparison to both inverting them and random orientation. The difference between upright and inversion was large and compelling.

There was less of a difference between upright and random orientation but upright still resulted in improved performance (Figures 13 & 14).

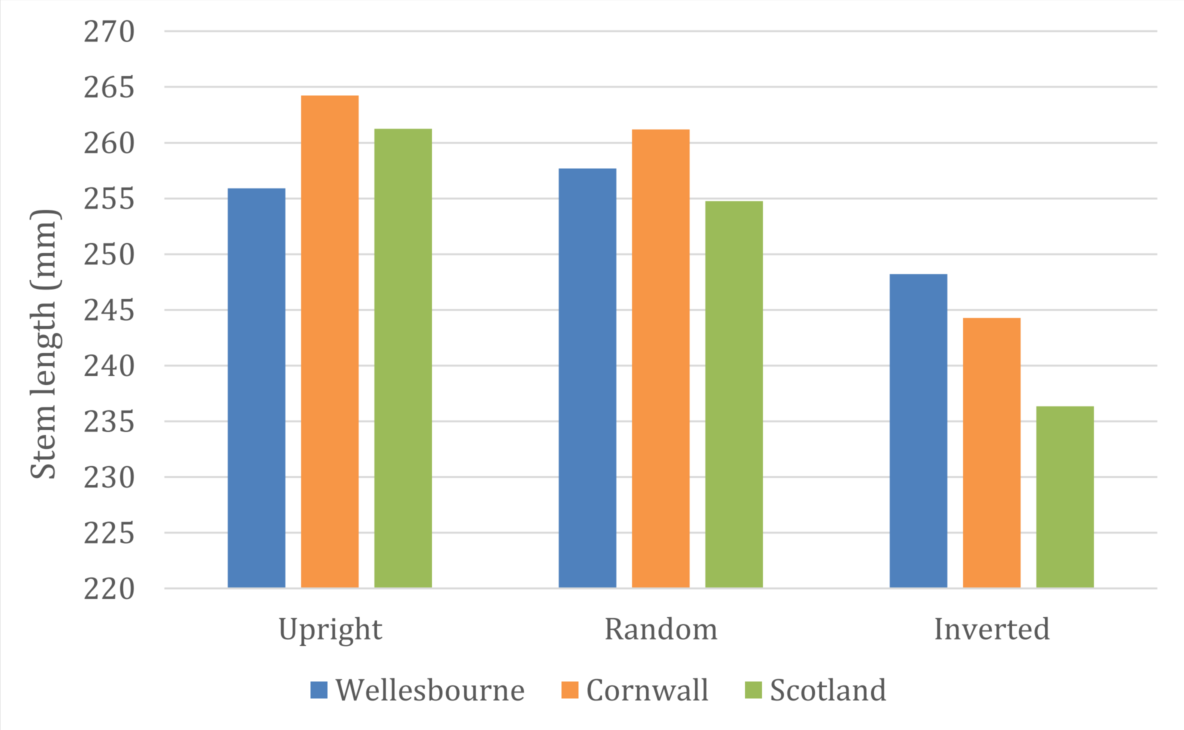

Figure 13. Year 1 flower harvest. The influence of bulb orientation at planting on stem length.

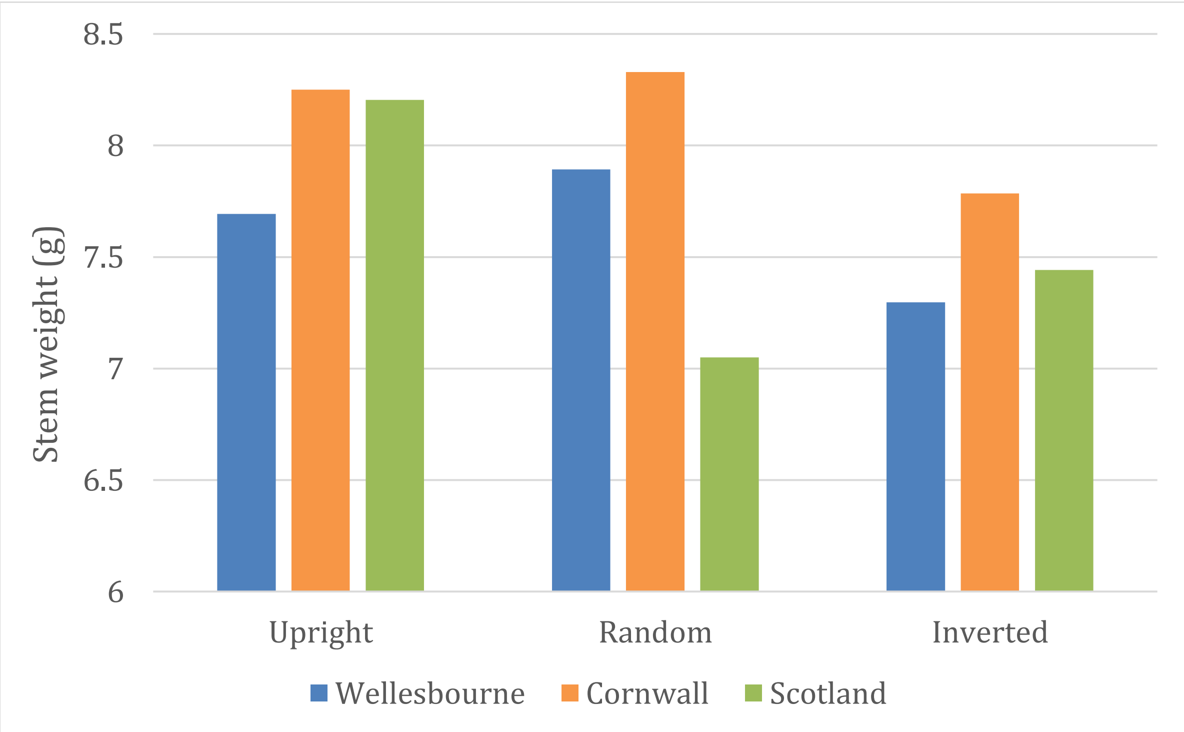

Figure 14. Year 1 flower harvest. The influence of bulb orientation at planting on stem weight.

Density also provided some clear results. Planting at 22 t/ha or greater produced more stems that were generally both longer and heavier (Figures 15 & 16). This suggests that typical commercial density of 17 t/ha may not be optimal for flower production, particularly in Cornwall, and that planting density could be increased if flower production is prioritised.

Depth provides less compelling evidence. The results suggest that 10cm can be detrimental to stem length but there is little difference between 15 and 20cm (Figures 17 and 18).

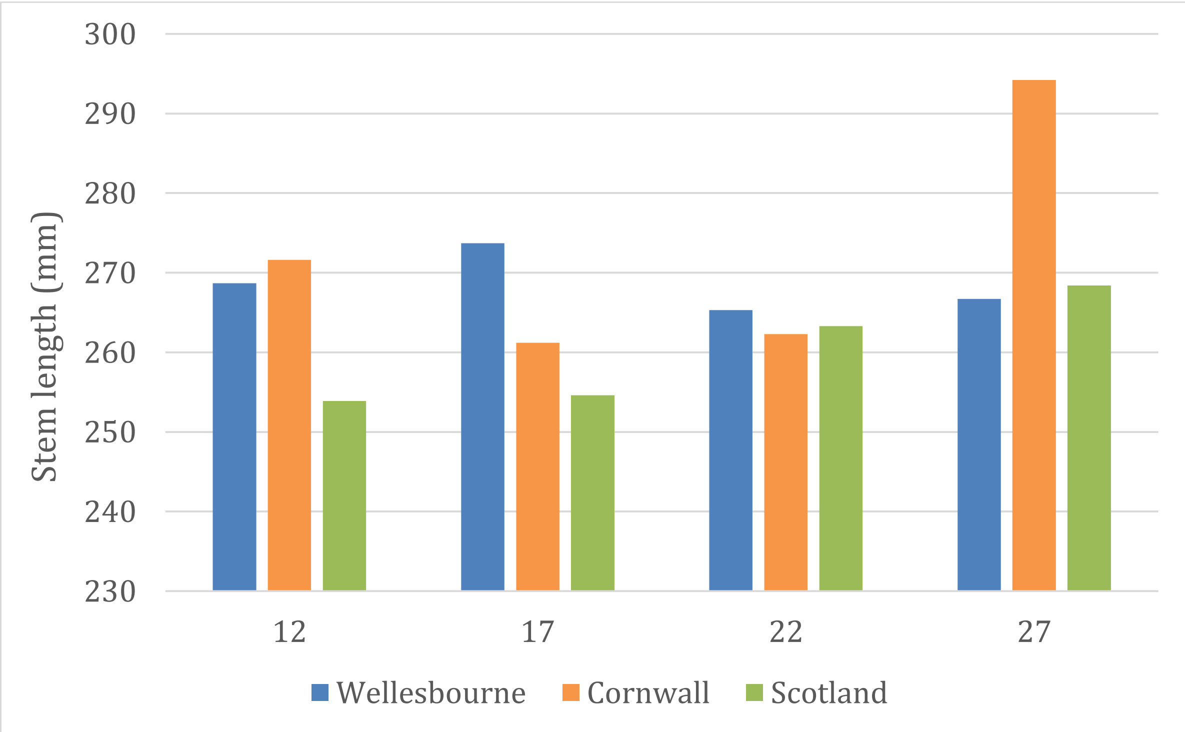

Figure 15. Year 1 flowers. The influence of bulb density (t/ha) at planting on stem length.

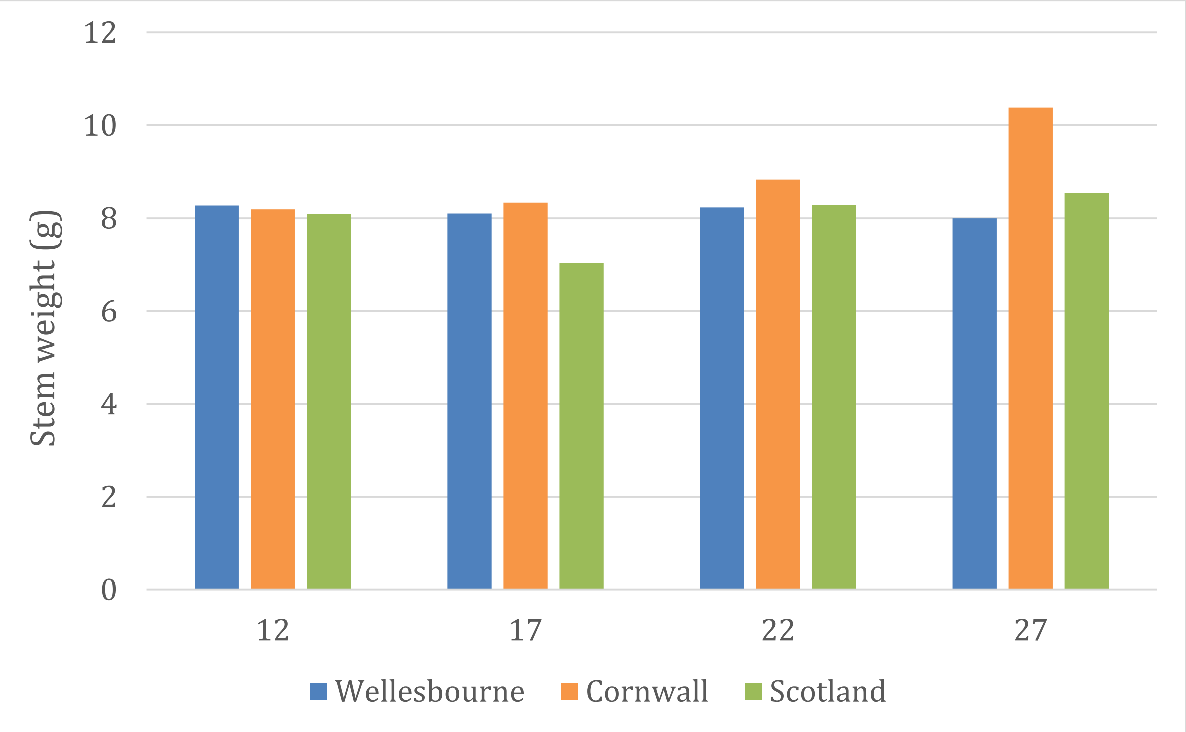

Figure 16. Year 1 flowers. The influence of bulb density (t/ha) at planting on stem weight.

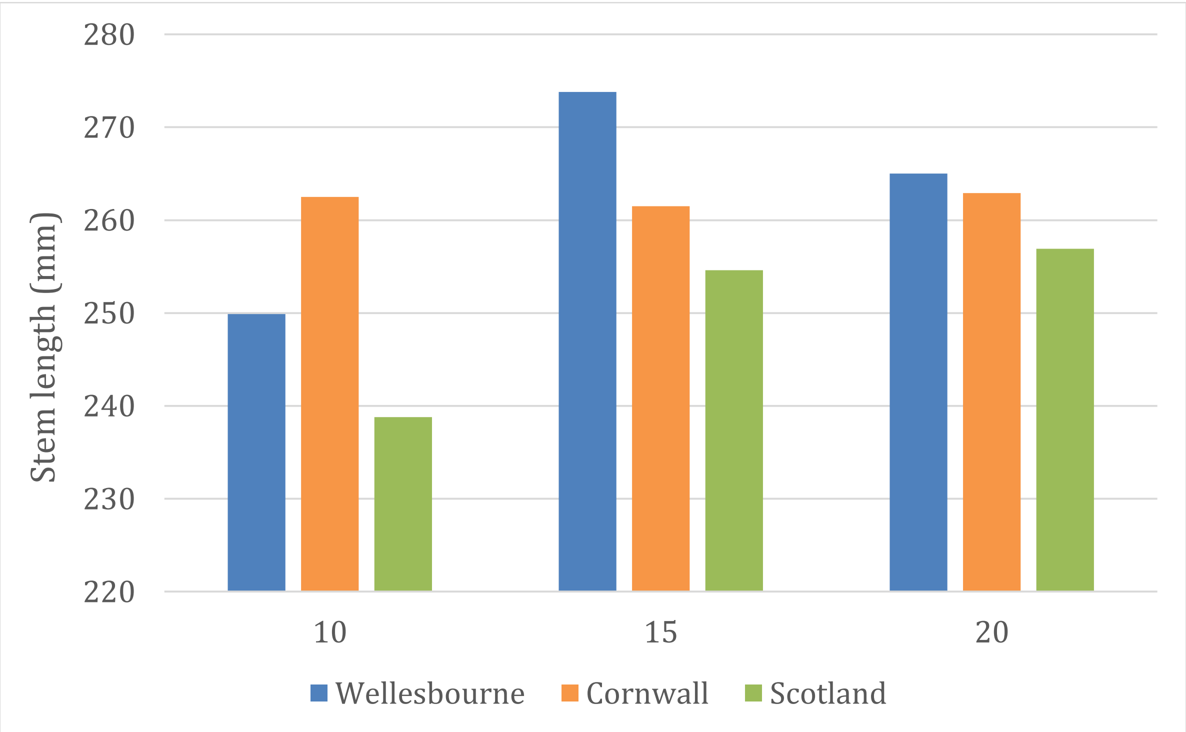

Figure 17. Year 1 flowers. The influence of bulb depth (cm) at planting on stem length.

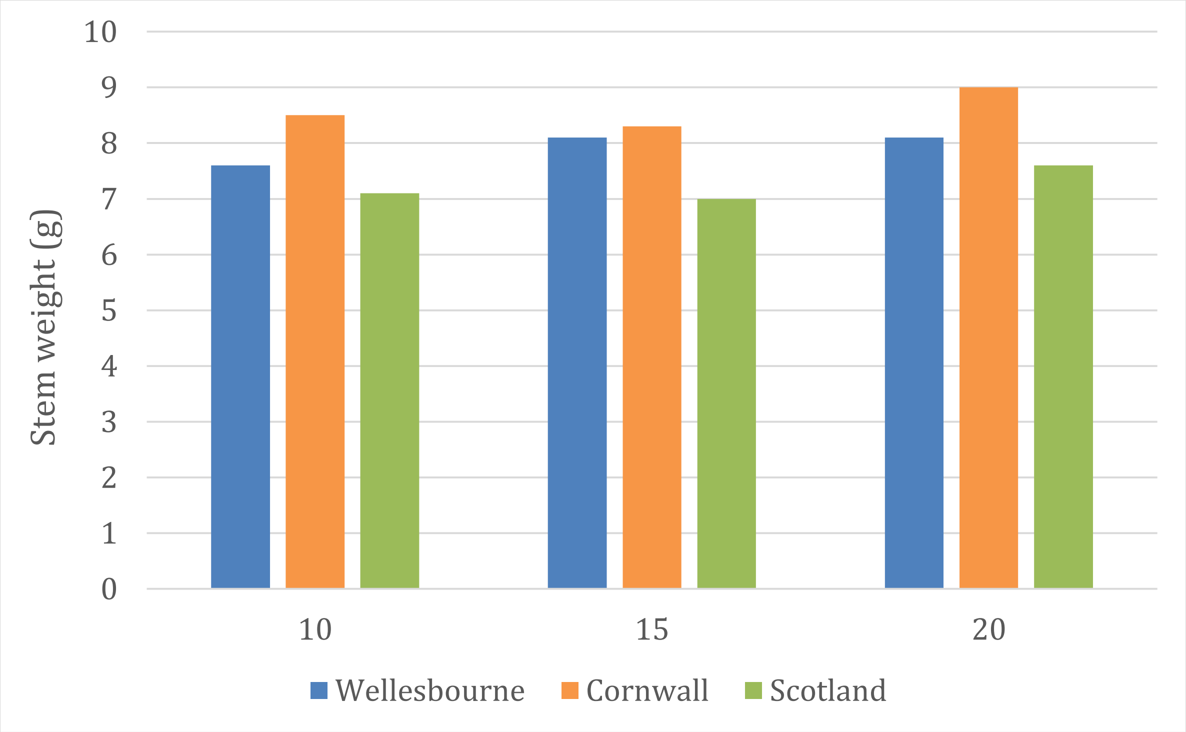

Figure 18. Year 1 flowers. The influence of bulb depth (cm) at planting on stem weight.

Flower harvest in spring 2016

Second year flower data was collected at Warwickshire only and used exactly the same methodology as the first year. The most noticeable difference was the lack of short, spindly flowers produced from the sides of the bulbs, compared to an abundance of them in year 1. The result was that second year data had slightly higher means and smaller variance compared to the first.

The results show that overall there were no significant differences between the treatments although some trends were apparent (Table 10). In terms of planting orientation, there was little to choose between random and upright orientation but both produced significantly more stems compared to inverted planting. Planting at 10cm also negatively impacted stem length in 'Dutch Master' although there was little difference between planting at 15cm and 20cm (Figure 19). The effect of planting density on stem length is difficult to interpret due to an unusual response at 22 t/ha but overall it's likely that planting density did not influence stem length (Figure 20).

Table 10. Warwickshire Data for *N.* 'Dutch Master' in year 2.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Number of stems	Stem length (mm)	Stem weight (g)
Control	15	17	Random	47.0	269.0	8.3
1	10	17	Random	28.7	239.5	8.1
2	20	17	Random	31.3	267.7	8.2
3	15	12	Random	16.7	269.0	8.0
4	15	22	Random	41.0	257.7	8.3
5	15	27	Random	36.7	268.1	8.4
12	10	17	Upright	35.3	253.1	7.8
13	10	17	Inverted	17.7	239.3	7.4
14	20	17	Upright	41.3	263.2	8.1
15	20	17	Inverted	15.3	261.4	8.0
All treatments; p=				n/a	0.009	0.558
Depth (Treatments C, 1 & 2); p=					0.087	0.714
Density (Treatments C, 3, 4 & 5); p=					0.621	0.920
Orientation (Treatments 1, 2, 12, 13, 14 & 15); p=					0.403	0.198

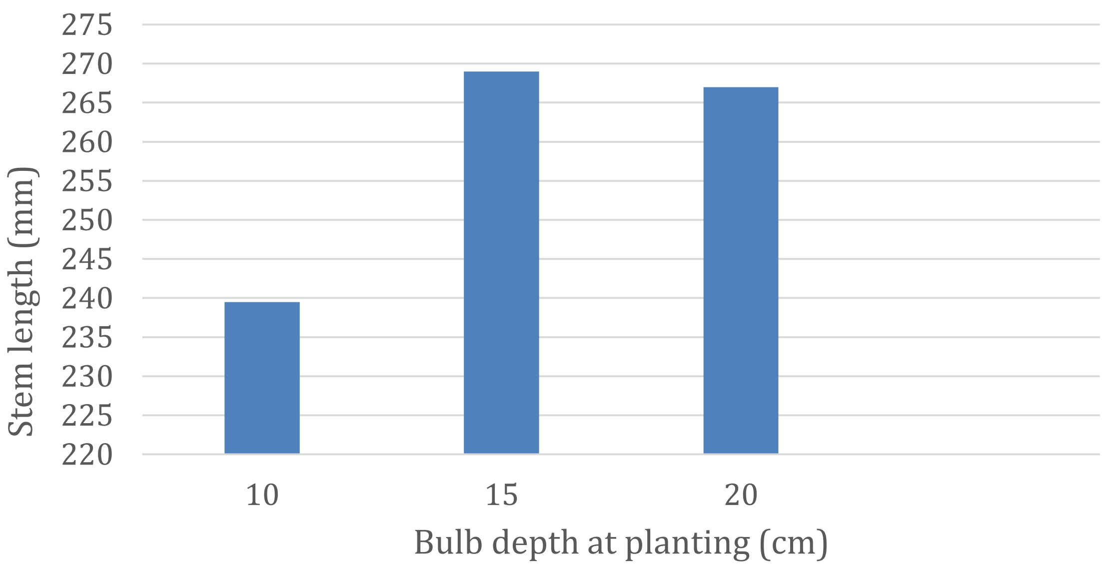

Figure 19. Year 2 flowers. The influence of bulb depth (cm) at planting on stem length.

Figure 20. Year 2 flowers. The influence of bulb density (t/ha) at planting on stem length.

No beneficial effect of upright planting of bulbs on the stem length at harvest was observed. However, there is evidence that inverted bulbs have reduced stem length compared to randomly planted controls (Figure 21). This is an unusual result and contrasts with the year 1 results which showed that upright orientation at planting provided a small benefit over random planting and a large benefit compared to inversion.

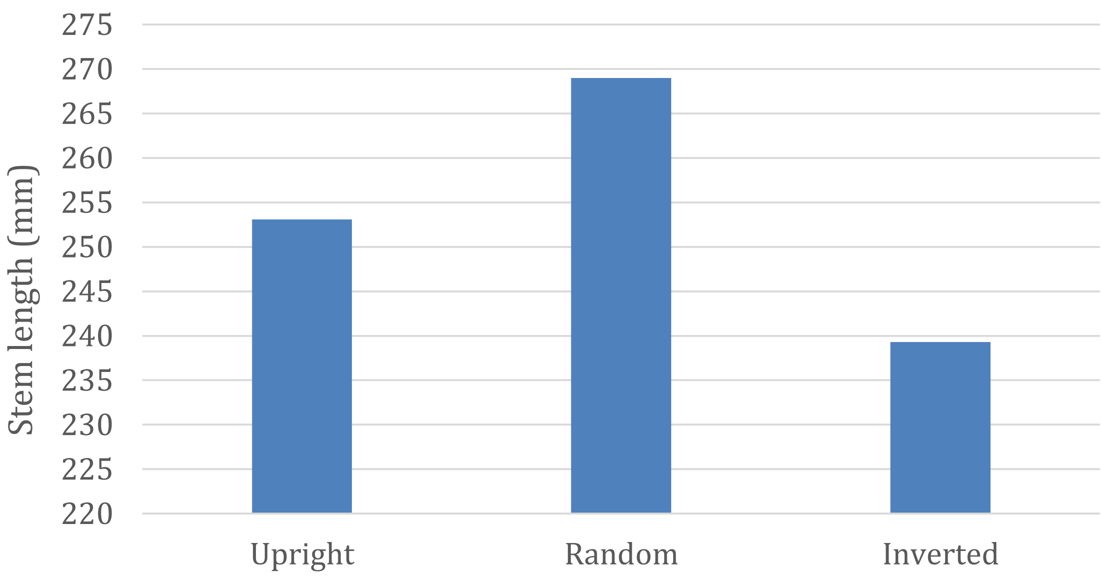

Figure 21. Year 2 flowers. The influence of orientation at planting on stem length.

Table 11. Data for *N.* ‘Carlton’

Treatments				Variables	
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Stem length (mm)	Stem weight (g)
Control	15	17	Random	301.1	9.5
1	10	17	Random	277.4	8.7
2	20	17	Random	294.9	8.8
3	15	12	Random	275.4	8.4
4	15	22	Random	305.2	9.8
5	15	27	Random	302.8	8.9
6	10	12	Random	271.3	8.4
7	10	22	Random	287.3	8.6
8	10	27	Random	283.2	8.4
9	20	12	Random	271.0	8.2
10	20	22	Random	296.2	9.1
11	20	27	Random	297.5	9.3
12	10	17	Upright	280.4	9.0
13	10	17	Inverted	276.1	8.2
14	20	17	Upright	300.6	9.7
15	20	17	Inverted	287.2	9.1
All treatments; p=				0.438	0.305
Depth (Treatments C, 1, 2, 6-11); p=				0.337	0.671
Density (Treatments C, 3-11); p=				<0.001	0.006
Orientation (Treatments C, 1, 2, 12-15); p=				0.214	0.258
Orientation/Density Interaction p=				0.488	0.763

The results clearly indicate that both low densities and shallow planting depth negatively affect stem length.

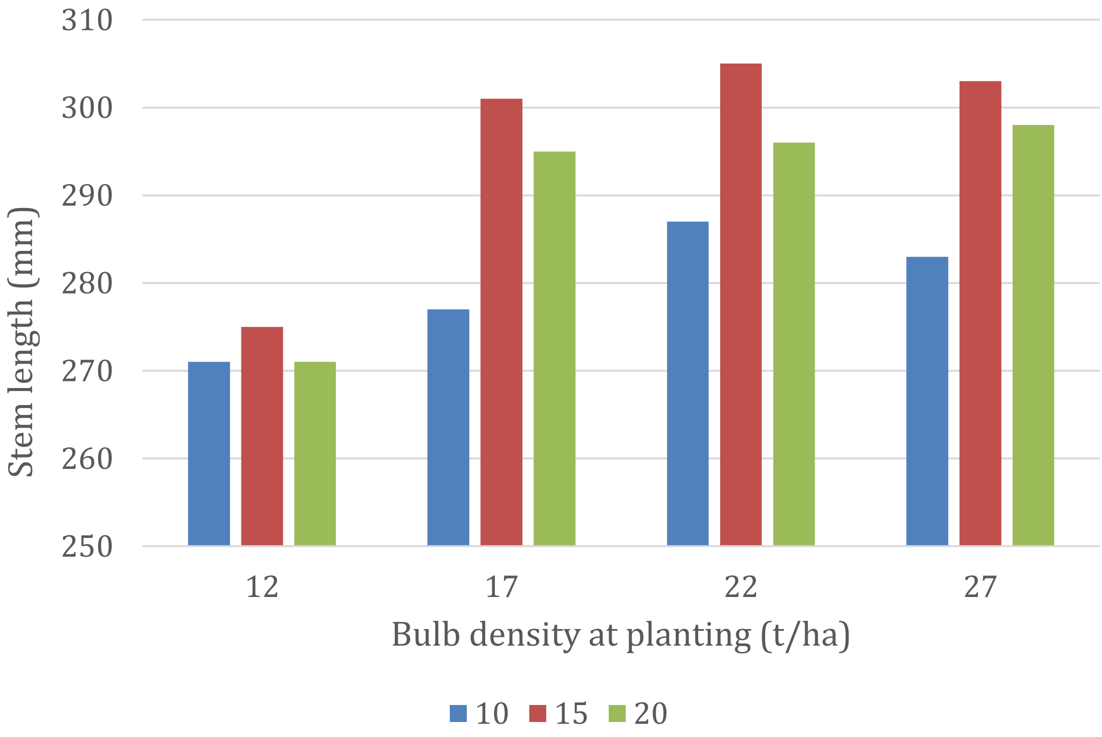

Figure 22. Year 2 flowers. The influence of bulb density (t/ha) and planting depth (cm) at planting on stem length.

Stem length is correlated with stem weight, and thus similar trends are evident for the same dataset.

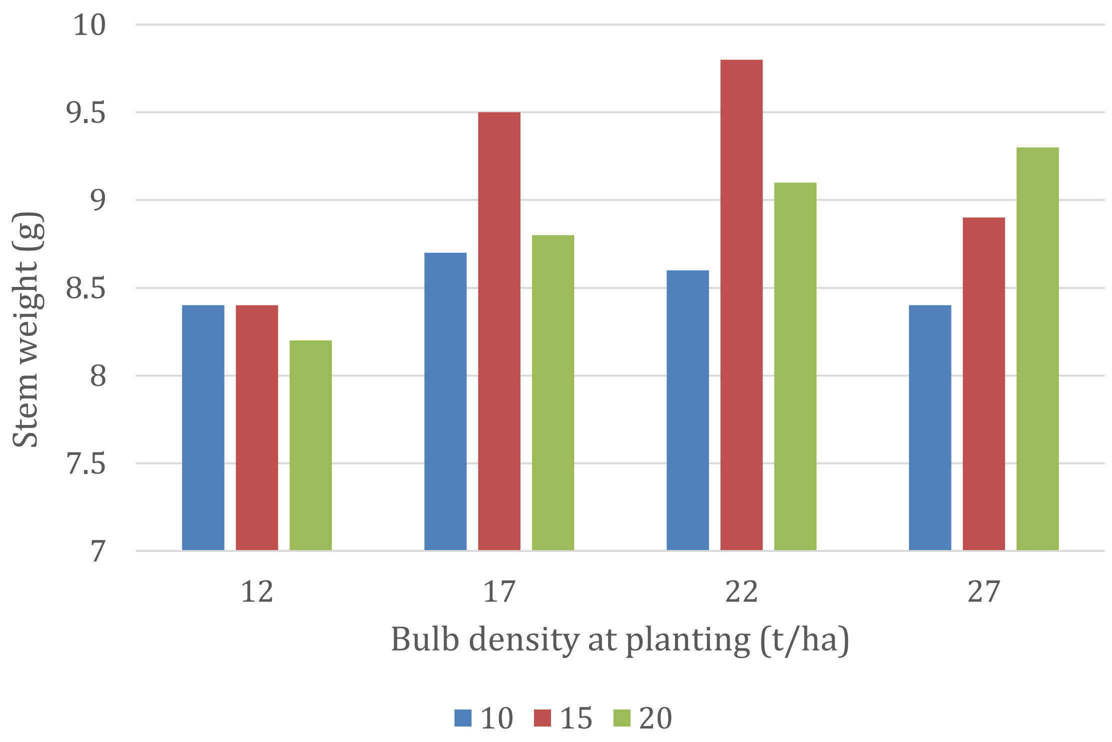

Figure 23. Year 2 flowers. The influence of bulb density (t/ha) and planting depth (cm) at planting on stem weight.

A number of different potassium fertiliser treatments were examined but there was little variation in the response to either rate or placement type. No statistically significant effect on stem length in *N.* 'Carlton' was found (Figure 24). There was some year-to-year variation, however, these were not consistent by year, so little can be inferred from the results. There was no difference between fertilised and unfertilised controls. Overall, the assumption was that the crop was never potassium deficient and that any differences are due to other factors.

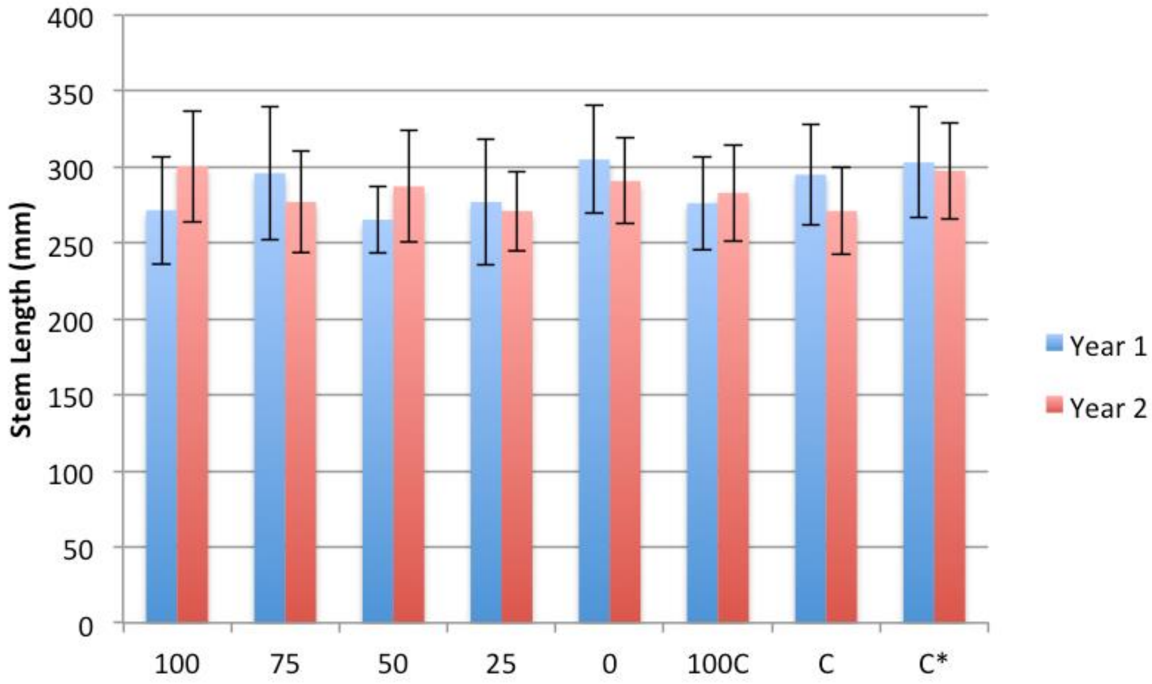

Figure 24. Year 2 flowers. The influence of plant nutrition on stem length.

Bulb harvest 2016: All location, main treatments

Bulbs, variety Dutch Master, were lifted after two years down and assessed for size and yield. This section reports on the three main treatments that were tested across all four locations; namely planting depth, planting density and orientation at planting. The treatments are:

- Planting depth: 10, 15 and 20 cm
- Planting density: 12, 17, 22 and 27 tonnes/hectare
- Planting orientation: upright, random and inverted

The results are discussed twice, firstly by location and secondly, by treatment. This approach allows the intra-location variation to be considered before moving on to discuss any inter-location differences.

Wellesbourne, Warwickshire

The bulbs from all treatments were lifted by hand the week commencing 27 June 2016. A few bulbs were excluded from assessment due to severe basal rot but we consider that this had little no or effect on the results. Overall, bulb yield at Warwickshire varied significantly by treatment with the highest and lowest yields being 16.8 and 36.9 t/ha respectively (Table 12).

Depth – Planting depth had a significant effect on both total bulb yield and increase in bulb yield. Bulb yield increased with planting depth by 16% from 21.8 t/ha at 10cm to 25.3 at 15cm and by 7% from 25.3 at 15 cm to 27.0 t/ha at 20cm. The difference in yield between 10cm and 15cm is significant, p= 0.031, but that between 15cm and 20cm is not, p=0.233. Deeper planting was also beneficial in terms of increasing bulb yield relative to planting density. Deeper planting resulted in more bulbs.

Density – Planting density had a significant effect on bulb yield at harvest with yield increasing with higher densities. Yield increased by 51% from 12 t/ha [16.8 t/ha] to 17 t/ha [25.3 t/ha], by 21% from 17 t/ha [25.3 t/ha] to 22 t/ha [30.7 t/ha] and by 20% from 22 t/ha [30.7 t/ha] to 27 t/ha [36.9 t/ha]. The differences in yield were all statistically significant, p=0.005, 0.010 and 0.092, respectively. Planting density did not have a major effect on the increase in bulb stock with similar percentage increases seen at each planting density.

Table 12. Warwickshire bulb harvest 2016. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Control	15	17	Random	25.3	8.3	49
1	10	17	Random	21.8	4.8	28
2	20	17	Random	27.0	10.0	59
3	15	12	Random	16.8	4.8	40
4	15	22	Random	30.7	8.7	40
5	15	27	Random	36.9	9.9	37
12	10	17	Upright	26.9	9.9	58
13	10	17	Inverted	22.1	5.1	30
14	20	17	Upright	29.8	12.8	75
15	20	17	Inverted	25.4	8.4	49
All treatments; p=				<.001	0.036	0.043
Depth (Treatments C, 1 & 2); p=				0.010	0.010	0.010
Density (Treatments C, 3, 4 & 5); p=				<.001	0.205	0.718
Orientation (Treatments 1, 12 & 13); p=				0.016	0.016	0.016
Orientation (Treatments 2, 14 & 15); p=				0.525	0.525	0.525

Orientation - Bulb orientation had a major effect on bulb yield. Planting the bulbs upright, rather than inverted, resulted in higher harvest yields, however, there were differences between the two planting depths. At a 10cm planting depth and at a typical planting density of 17 t/ha, upright planting resulted in a significantly higher yield compared to both random and inverted planting, 23% and 22% respectively. However, at a 20cm planting depth the margin for upright over random and inverted was reduced to 10% and 17% respectively. Orientating the bulbs upright at planting generated higher bulb yields in comparison to random or inverted with a particularly strong advantage at the 10cm planting depth. But, planting at 20cm depth always resulted in higher yields in comparison to 10cm whatever the orientation.

In summary: Bulb yields were influenced by all three treatments; deeper planting at higher densities and in an upright orientation produced the highest yields. The greatest increase in bulb yield, relative to planting weight, came from planting at 20cm and planting upright. The smallest increase came from shallowed planting, 10cm in this trial. Any disadvantage from random or inverted planting can be mostly corrected by planting at higher densities.

Plots where bulbs had been inverted at planting had a high incidence of neck rots. Excavation of bulbs revealed that where the stem had twisted and turned in an effort to reach the soil surface, cracks and lesions occurred which became infected (Figure 25). A proportion of stems never reached the soil surface which had a negative effect on both flower and bulb production.

Figure 25. In-situ bulbs at Warwickshire showing inverted orientation and signs of neck rot.

Laurencekirk Aberdeenshire

The bulbs from all treatments were lifted by hand on 5 July 2016. The bulbs were very clean and none were excluded from assessment. Overall, bulb yield in the Scottish trial varied significantly by treatment with the highest and lowest yields being 36.2 and 57.6 t/ha respectively (Table 13).

Depth – Planting depth had a clear, if not statistically significant, effect on both total bulb yield and increase in bulb yield. The highest bulb yield of 48.5 t/ha was achieved by planting at 15cm with shallower and deeper planting decreasing the yield a little; planting at 10cm and 20cm depressed bulb yield by 12% (p=0.031) and 5% respectively. Planting at 15cm also provided the greatest increase in bulb yield at 185% of planting density. The smallest increases occurred when planting at 10cm.

Density – Planting density had a significant effect on bulb yield at harvest with yield increasing with higher densities. Yield increased by 34% from 12 t/ha [36.2 t/ha] to 17 t/ha [48.5 t/ha], by 13% from 17 t/ha [48.5 t/ha] to 22 t/ha [54.8 t/ha] and by 5% from 22 t/ha [54.8 t/ha] to 27 t/ha [57.6 t/ha]. The differences in yield were not all statistically significant, p=0.005, 0.134 and 0.509, respectively, but do demonstrate that planting density has a real effect on yield. Planting density also had a major effect on the increase in bulb stock, relative to planting density; the highest increase was observed with the lowest planting density and vice versa.

Orientation - Inverting bulbs at planting depressed yield in comparison to either random or upright planting but the differences were relatively small. The major result was a significant 13% reduction in yield between random [48.5 t/ha] and inverted [42.2 t/ha] planting. The difference between upright and inverted planting was not significant (p=0.398).

Table 13. Laurencekirk bulb harvest 2016. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Control	15	17	Random	48.5	31.5	185
1	10	17	Random	42.8	25.8	152
2	20	17	Random	45.9	28.9	170
3	15	12	Random	36.2	24.2	202
4	15	22	Random	54.8	32.8	149
5	15	27	Random	57.6	30.6	113
12	15	17	Upright	45.4	28.4	167
13	15	17	Inverted	42.2	25.2	149
All treatments; p=				<.001	0.079	0.003
Depth (Treatments C, 1 & 2); p=				0.057	0.057	0.057
Density (Treatments C, 3, 4 & 5); p=				<.001	0.092	0.003
Orientation (Treatments C, 12 & 13); p=				0.167	0.167	0.167

In summary: Bulb yield was influenced by all three main treatments but the pattern was different to Warwickshire. The optimum planting depth in Scotland was 15cm with yield declining a little at shallower and deeper depths. Bulb yield increased with planting density as expected and the pattern of increase was as expected; the greatest increases in stock came from the least dense planting. However, unlike Warwickshire, orientation at planting was less of a factor and random orientation resulted in higher yields than either upright or inverted planting

Spalding, Lincolnshire

The bulbs from all treatments were lifted by hand on 18 July 2016. The bulbs were very clean and none were excluded from assessment. Overall, bulb yield in Lincolnshire varied by treatment with the highest and lowest yields being 35.5 and 47.2 t/ha respectively (Table 14).

Depth – Bulb yield did increase with increasing planting depth but the differences in yield between the three depths was not statistically significant. The difference between the lowest and highest yield was only 2.6 t/ha.

Density – The results for planting density were mixed. The biggest increase in bulb yield, relative to planting density, came from lowest plant density (12 t/ha) and this inverse trend was true at all densities. However, the control density (17 t/ha) performed relatively poorly in comparison to 12 t/a.

Orientation – The different orientation treatments had no effect on bulb yield and both upright and inverted planting performed as well as random orientation.

Table 14. Spalding bulb harvest 2016. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Control	15	17	Random	37.5	20.5	120
1	10	17	Random	35.5	18.5	109
2	20	17	Random	38.1	21.2	124
3	15	12	Random	39.8	27.8	231
4	15	22	Random	47.2	25.2	114
5	15	27	Random	44.2	17.2	64
12	15	17	Upright	37.9	20.9	123
13	15	17	Inverted	38.3	21.3	125
All treatments; p=				0.456	0.521	0.023
Depth (Treatments C, 1 & 2); p=				0.688	0.688	0.688
Density (Treatments C, 3, 4 & 5); p=				0.441	0.323	0.036
Orientation (Treatments C, 12 & 13); p=				0.981	0.981	0.981

In summary: The variation between treatments yields was the smallest of all four locations and the treatment effects were less pronounced. The response to the depth or orientation treatments were negligible and the density treatments performed mostly to expectation. However, despite the lack of differences, overall performance and bulb yield were very good.

Truro, Cornwall

The bulbs from all treatments were lifted by hand on 11 July 2016. A very small number of bulbs were excluded from assessment due to severe basal rot but we consider that this had no effect on the results. Overall, bulb yield in Cornwall varied significantly by treatment with the highest and lowest yields being 15.3 and 35.1 t/ha respectively (Table 15).

Depth – Planting depth had a significant but confusing effect on bulb yield. The highest yield was obtained at the deepest depth (20cm) but the lowest yield was obtained at 15cm which was unexpected. Planting at 20cm resulted in a 35% and 22% greater yield in comparison to 15cm and 10cm respectively.

Density – The effect of different planting density on the increase in bulb yield was mixed. The largest increase was observed at the lowest density as expected but other results were mixed, e.g. the second greatest increase occurred at the highest planting density.

Orientation - The effect of different bulb orientation at planting was significant with upright planting resulting in a 21% and 33% greater yield in comparison to random and inverted planting respectively.

Table 15. Truro bulb harvest 2016. Main treatments.

Treatments				Variables		
Treatment number	Depth (cm)	Density (t/ha)	Orientation	Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Control	15	17	Random	18.2	1.2	7
1	10	17	Random	22.1	5.1	30
2	20	17	Random	28.2	11.2	66
3	15	12	Random	18.9	6.9	57
4	15	22	Random	27.3	5.3	24
5	15	27	Random	35.1	8.1	30
12	15	17	Upright	22.9	5.9	35
13	15	17	Inverted	15.3	-1.7	-10
All treatments; p=				0.002	0.040	0.045
Depth (Treatments C, 1 & 2); p=				0.079	0.079	0.079
Density (Treatments C, 3, 4 & 5); p=				0.015	0.274	0.245
Orientation (Treatments C, 12 & 13); p=				0.271	0.271	0.271

In summary: Cornwall data resulted in some mixed messages but overall support deeper and upright planting.

All locations

All four locations provided different soil and climatic conditions and this is reflected in the variation in the results. Means for the harvest variables are shown in Table 16 and demonstrate that the same starting conditions resulted in very different outcomes. The difference between the lowest and highest bulb weight was 23.2 t/ha and in effect the bulb yield in Scotland was double that of Cornwall with the other two sites fitting in between. This huge difference is driven primarily by soil quality with perhaps disease being an additional factor. This division has long been recognised by growers but it is satisfying to see it represented in the results. The fertile soils present in Scotland and Lincolnshire provided a good environment for increasing bulb stocks, with rates of increase being 161% and 127%

respectively, which is in complete contrast to the sites at Warwickshire and Cornwall where increases were far smaller. In terms of site performance for bulb production, Scotland provided the highest yields, followed by Lincolnshire, Warwickshire and Cornwall.

Table 16. Summary statistics for bulb harvest results by location.

Location	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Warwickshire	24	25.9	7.7	43
Scotland	24	46.7	28.4	161
Lincolnshire	22	39.5	21.4	127
Cornwall	16	23.5	5.2	29

Bulb depth at planting

The combined bulb harvest results from across all sites for the depth treatments are presented in Table 17 and Figures 17, 18 and 19. Despite the huge difference in bulb yield between the sites and the relatively poor performance at 15cm in Cornwall, there is a recognisable relationship between planting depth at harvest and bulb yield at two years. Bulb yield and the increases in yield increase with deeper planting.

Table 17. Bulb harvest results for depth treatment across all four sites.

Depth	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
10	32	31.3	14.3	84
15	32	33.7	16.7	98
20	32	35.4	18.4	108
All sites; p=		0.644	0.644	0.644

The gains are marginal, ranging between 5% and 17%, but are real and deeper planting, up to 20cm, can be recommended.

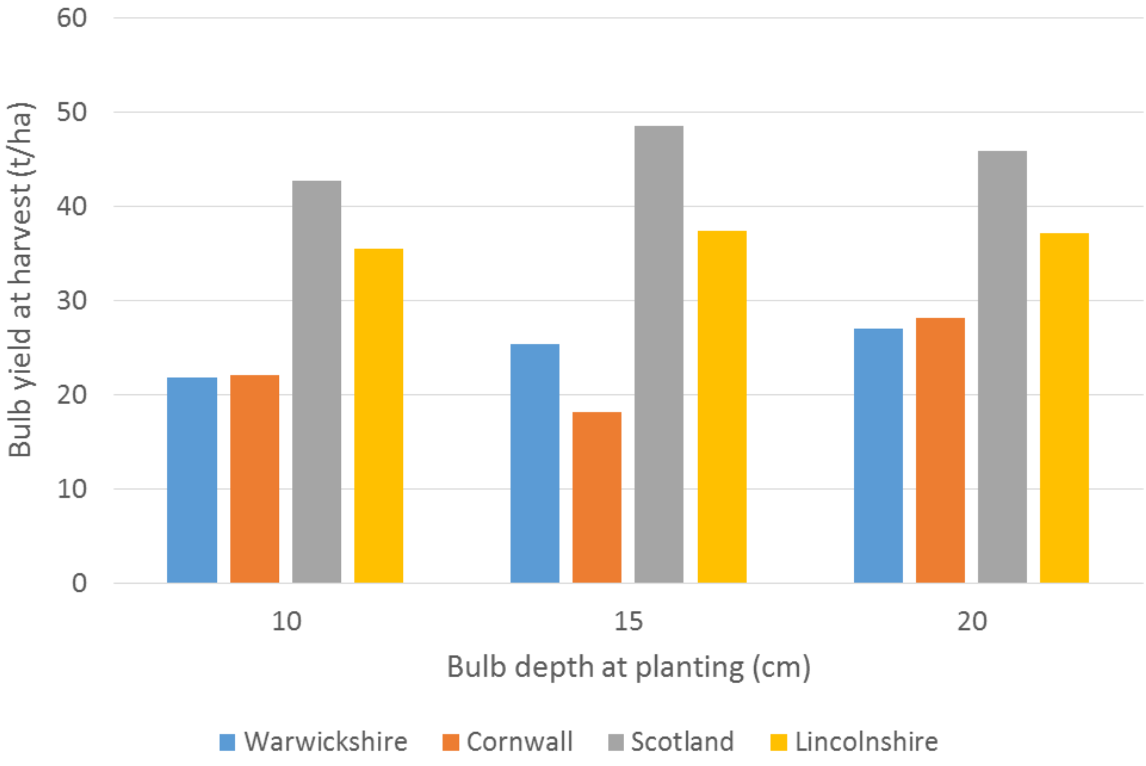

Figure 26. Year 2 bulb harvest. The influence of bulb depth at planting on bulb yield at harvest (t/ha).

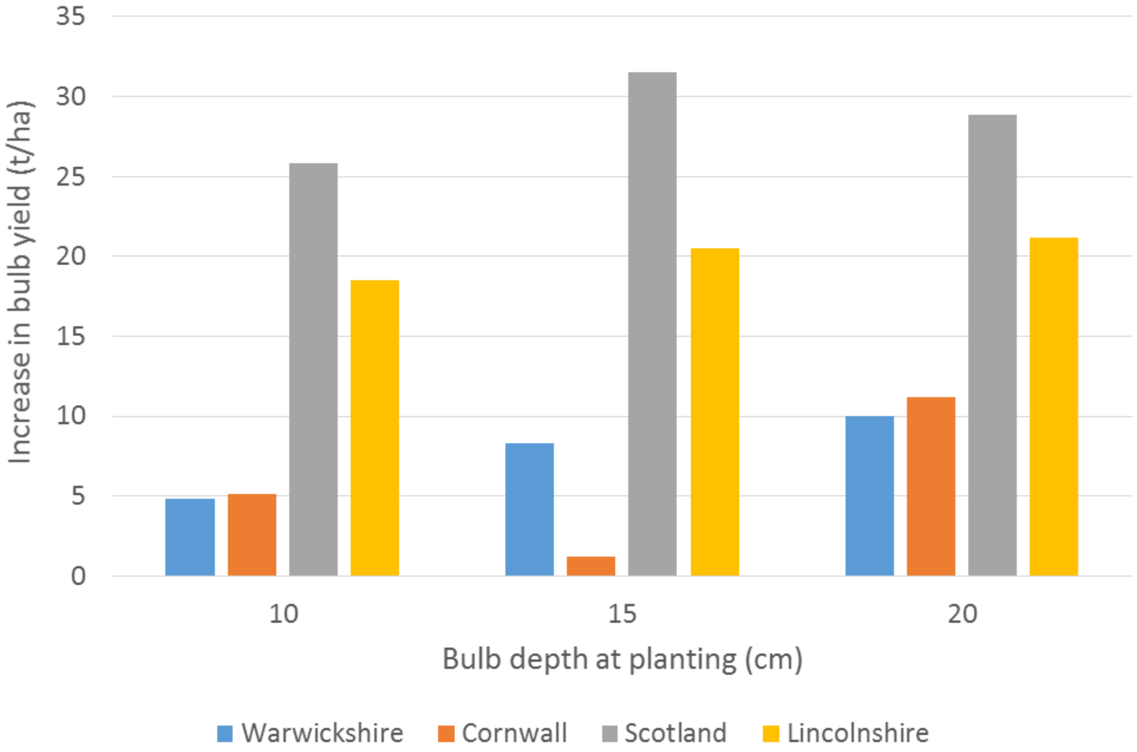

Figure 27. Year 2 bulb harvest. The influence of bulb depth at planting on the increase in bulb yield at harvest (t/ha).

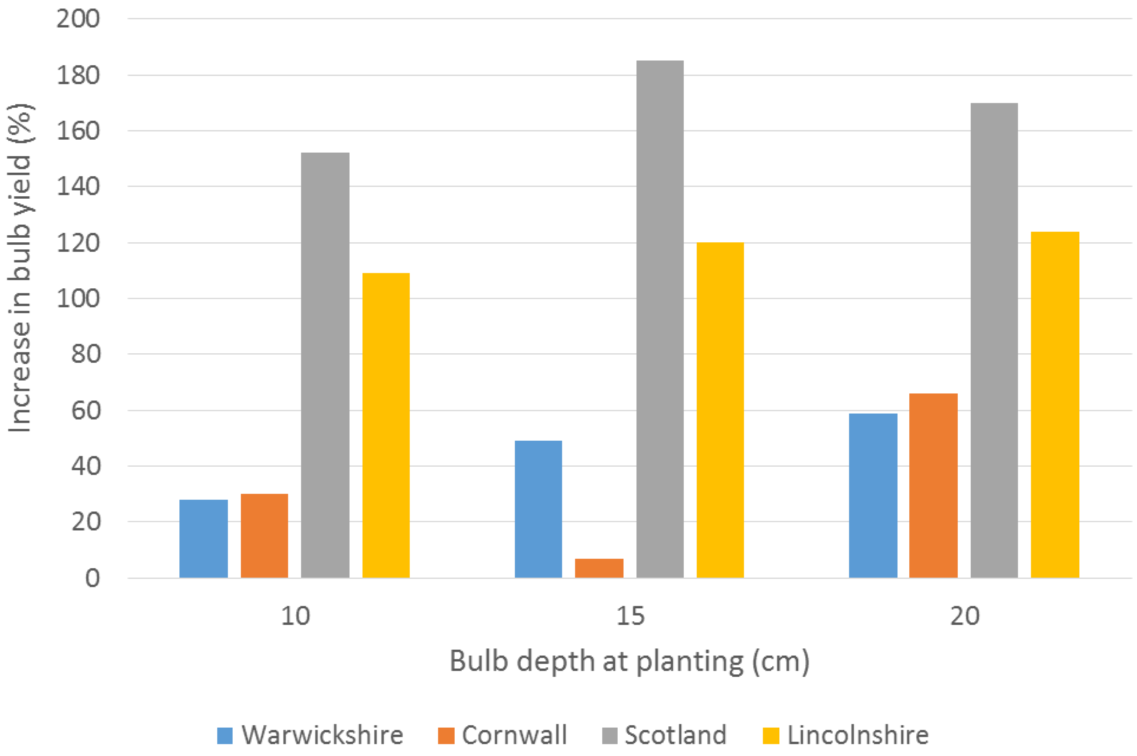

Figure 28. Year 2 bulb harvest. The influence of bulb depth at planting on the increase in bulb yield at harvest (%).

Bulb density at planting

The combined bulb harvest results from across all sites for the density treatments are presented in Table 18 and Figures 20, 21 and 22. Despite the poor performance of 17 t/ha in Cornwall, the results are textbook in nature and mostly match expectation. Total bulb yield at harvest increased with planting density as does the increase in yield relative to the starting density. The consistency in the yield increase is perhaps a little surprising at the higher densities suggesting that if increases in bulb stock were the primarily objective, then even higher densities than 27 t/ha could be considered.

Table 18. Bulb harvest results for density treatment across all four sites.

Density	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
12	43	28.7	16.7	139
17	43	33.7	16.7	98
22	43	40.5	18.5	84
27	43	44.2	17.2	64
All sites; p=		0.017	0.981	0.099

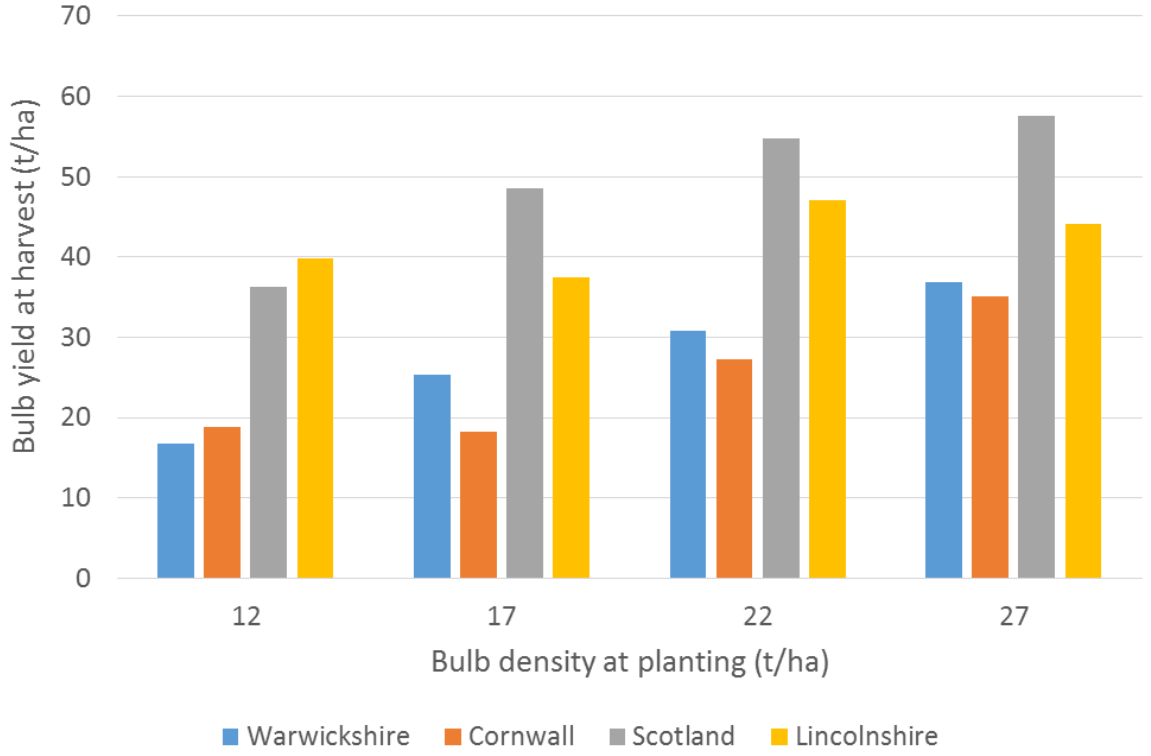

Figure 29. Year 2 bulb harvest. The influence of bulb density at planting (t/ha) on bulb yield at harvest (t/ha).

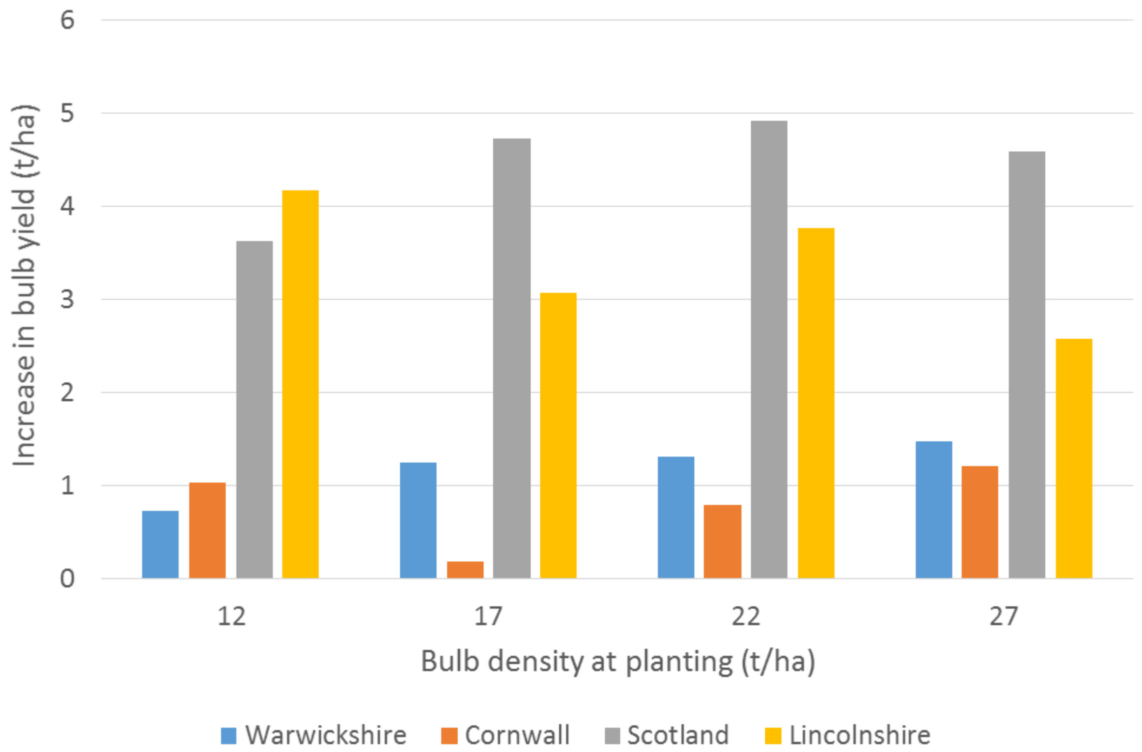

Figure 30. Year 2 bulb harvest. The influence of bulb density (t/ha) on the increase in bulb yield at harvest (t/ha).

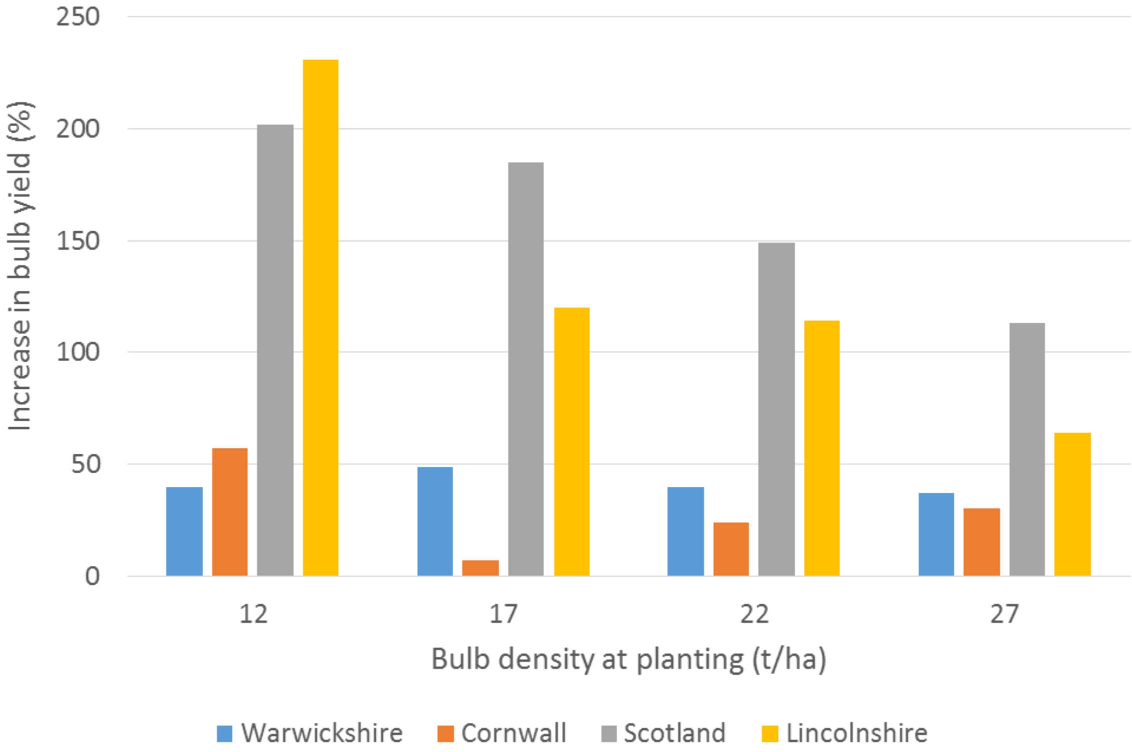

Figure 31. Year 2 bulb harvest. The influence of bulb density (t/ha) on the increase in bulb yield at harvest (%).

An analysis of variance was used to examine the effects of depth and density on bulb yield in *N.* 'Carlton', to see if there were any interaction between the two. A highly significant effect was found for the effects of density, but no effect of depth was detected, nor any interaction.

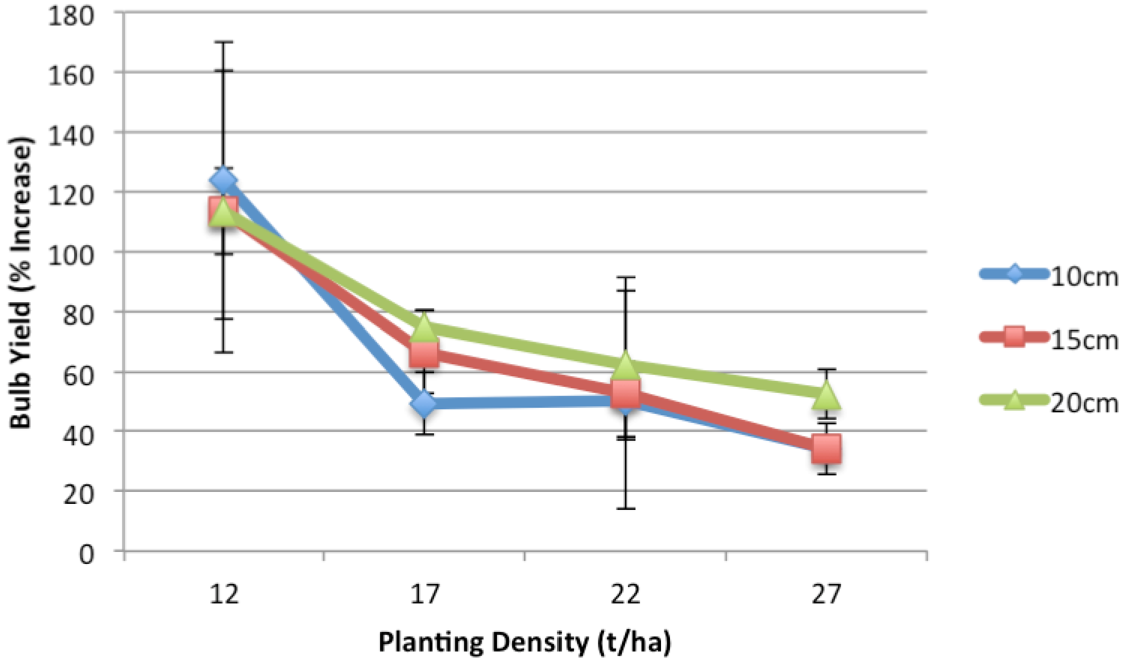

Figure 32. Year 2 bulb harvest. The influence of bulb density (t/ha) and planting depth (cm) on the increase in bulb yield at harvest (%) for variety Carlton

Bulb orientation at planting

The combined bulb harvest results from across all sites for the density treatments are presented in Table 19 and Figures 23, 24 and 25. The results are clear if not statistically significant; planting bulbs upright and at random orientation produces better yields and increases in yield. Field observations back this up. Inverted bulbs at harvest had either shorter twisted stems or in many cases, the stem had failed to reach the soil surface. While no grower deliberately inverts bulbs at planting, there is an advantage to ensuring that as many bulbs as possible are planting upright or at least on their side as this undoubtedly reduced the energy required to successfully establish the bulb in the ground.

Table 19. Bulb harvest results for orientation treatment for all varieties across all four sites.

Orientation	Number of observations	Mean of variables		
		Bulb weight (t/ha)	Increase in bulb yield (t/ha)	Increase in bulb yield (%)
Upright	55	31.6	14.6	85.8
Random	55	29.5	12.5	73.4
Inverted	55	27.6	10.6	62.6
All sites, all three orientations; p=		0.469	0.469	0.469
All sites, upright and inverted; p=		0.209	0.209	0.209

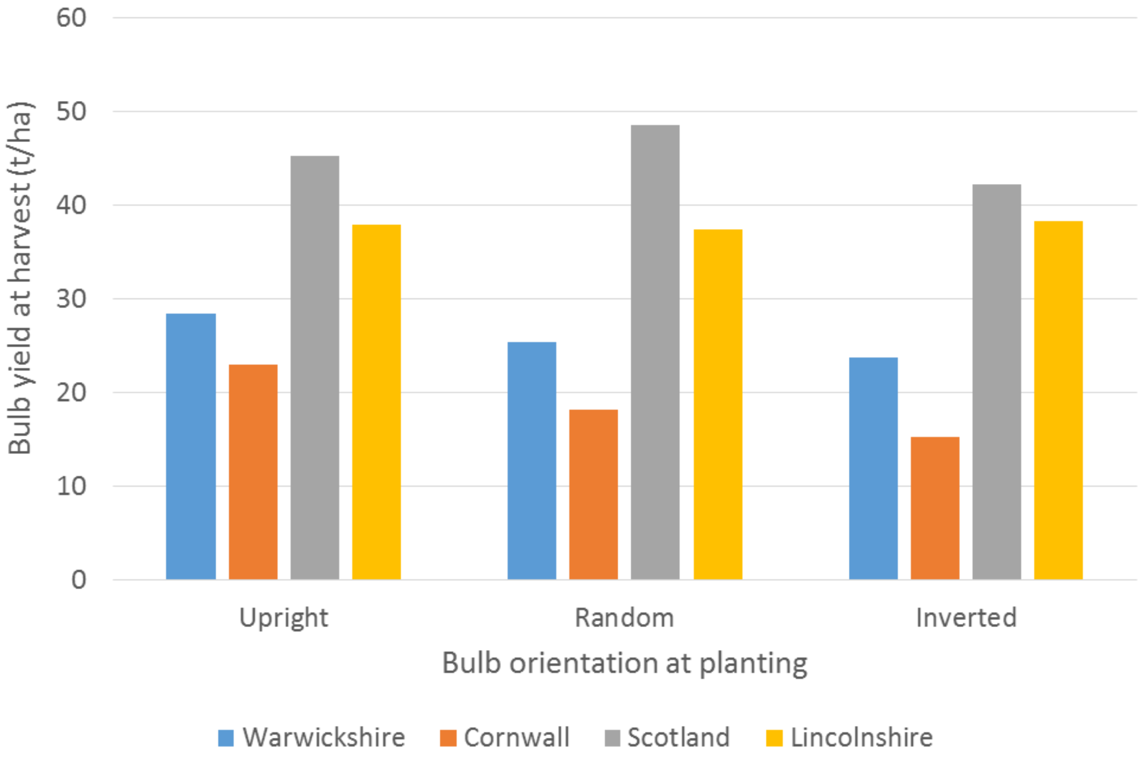

Figure 33. Year 2 bulb harvest. The influence of bulb orientation on bulb yield at harvest (t/ha).

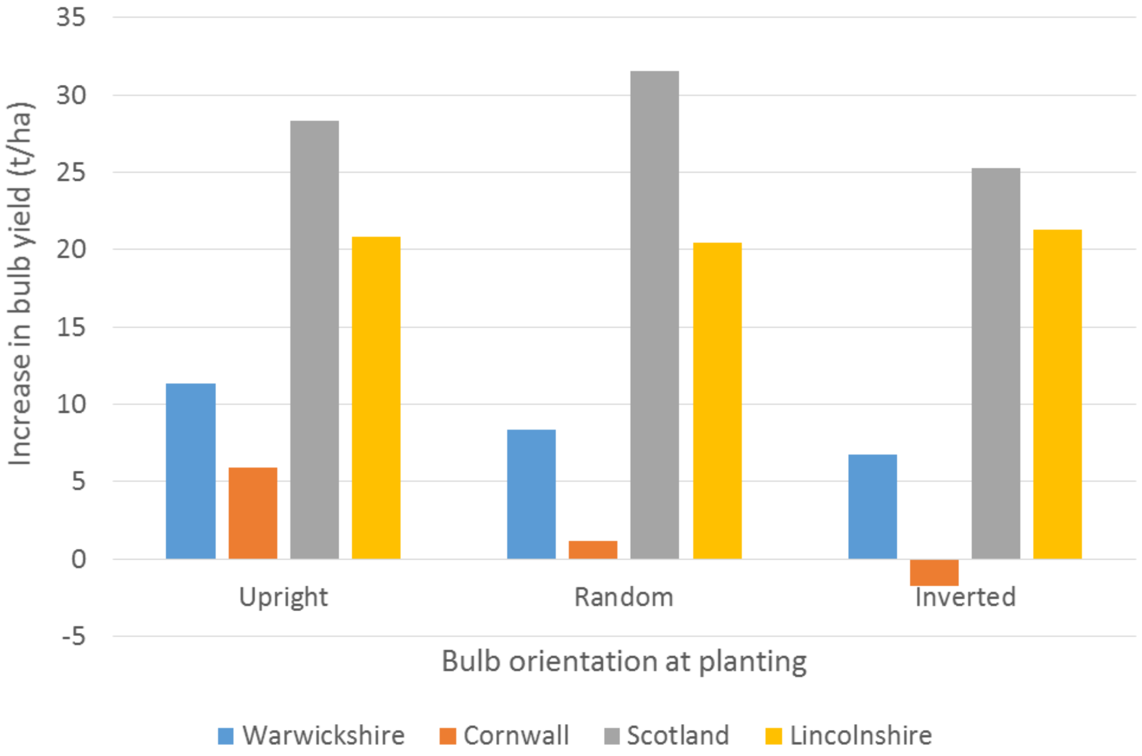

Figure 34. Year 2 bulb harvest. The influence of bulb orientation on the increase in bulb yield at harvest (t/ha).

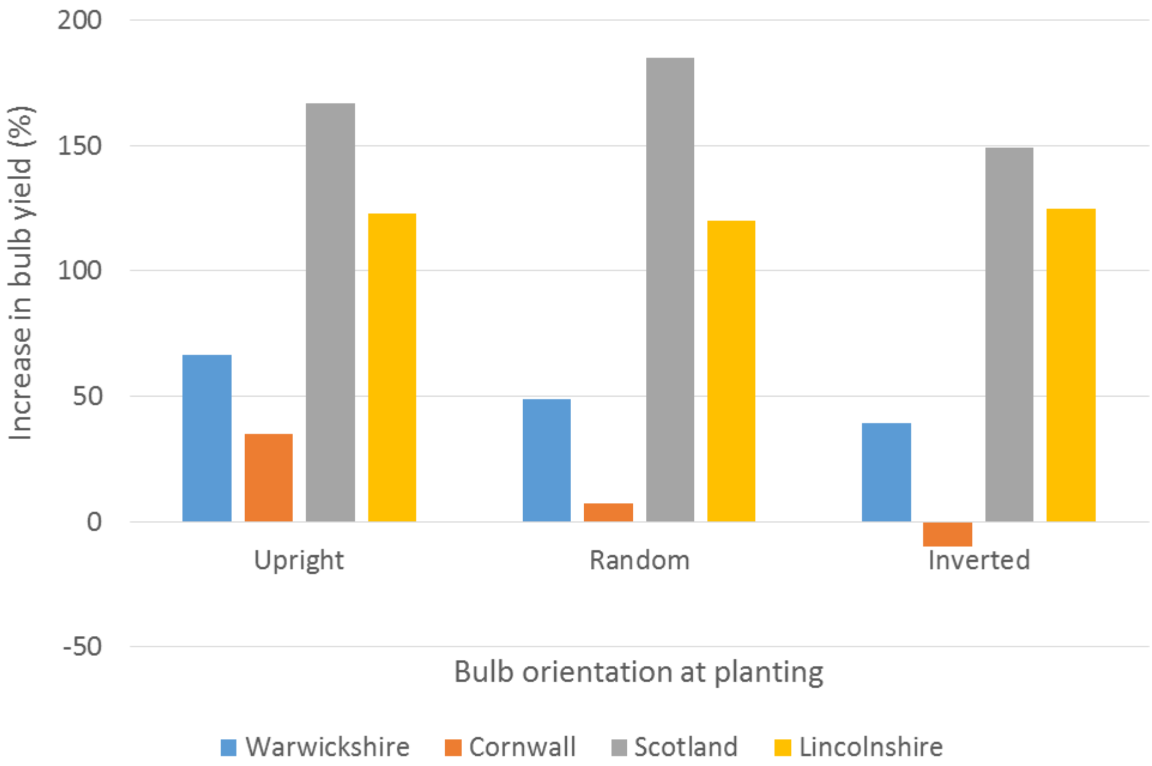

Figure 35. Year 2 bulb harvest. The influence of bulb depth at planting on the increase in bulb yield at harvest (%).

Fertiliser Placement

No effect of fertiliser placement was observed on either flower production or bulb yield. Previous research suggests bulbs respond to potassium application, and the lack of any effect may be due to another factor limiting bulb growth in the experiment, movement of potassium through the soil between treatments or roots drawing on deeper reserves of potassium within the soil – below the sampling depth used to calculate application rates.

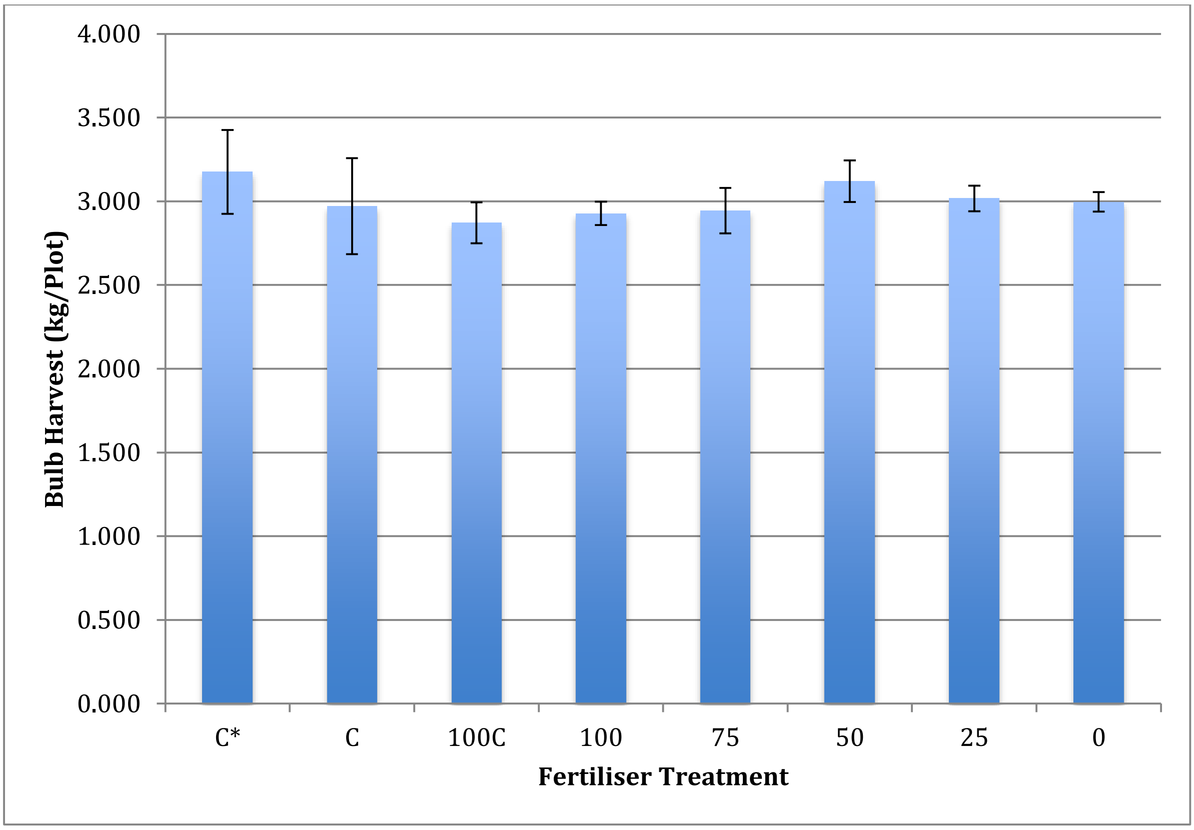

Figure 36. Effect of fertiliser placement on bulb yield. Key: C* = Broadcast control, main experiment, C = Simulated broadcast control, 100C = 100% Application rate in direct contact with bulbs, other symbols are relative SOP application rates, as % of control.

Post HWT drying

Bulbs that were warm-stored after HWT suffered severe bulb losses, which is reflected in the yield data. Bulbs dried at ambient temperatures generally fared better, although those planted just 24 hours after HWT also suffered poor yields, versus those stored for longer. This is surprising, since long storage and late planting would be expected to impact yields.

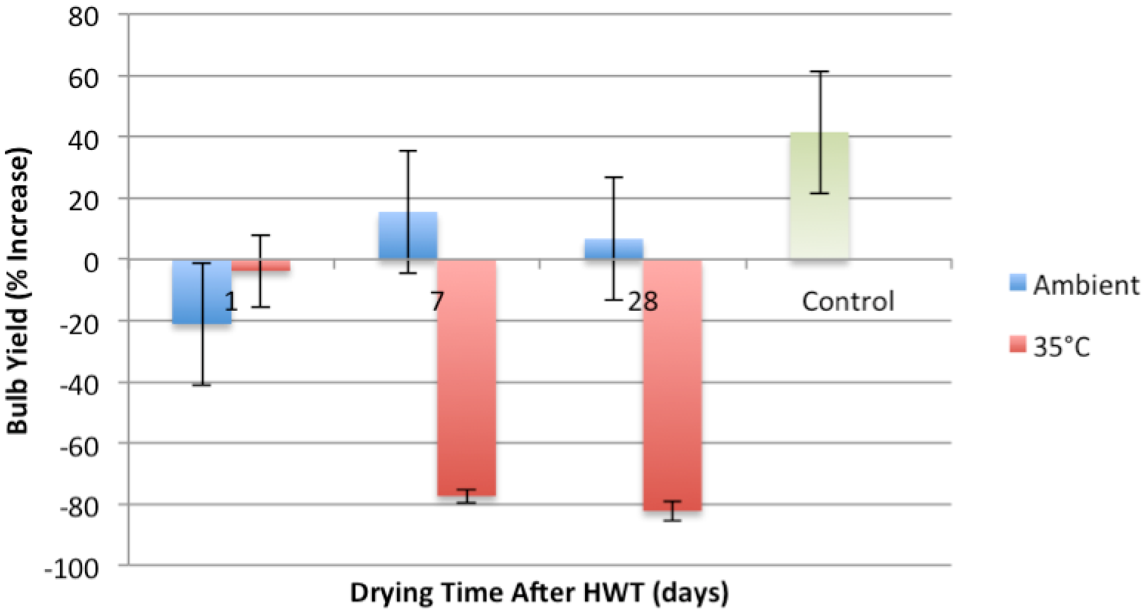

Figure 37. The effect of drying time and temperature post HWT on the increase in bulb yield for Carlton.

Discussion and conclusions

This section reports the results of field trials carried out between summer 2014 and summer 2016. The trial design involved multiple replicated treatments across four sites in Warwickshire, Cornwall, Lincolnshire and Scotland. The trial was based on two flower harvests, spring 2015 and spring 2016, and a final bulb harvest in early summer 2016. Due to operational problems, the data for the spring 2015 flower harvest in Lincolnshire and the spring 2016 flower harvests in Lincolnshire, Cornwall and Scotland are missing from this analysis. This obviously detracts from the results, however, all harvests in Warwickshire were complete so the conclusions and recommendations are considered robust.

Three planting depths were examined: 10, 15 and 20cm. Planting depth did effect first year flower production with the best results found at 15cm and 20cm. Planting depth was also a factor in bulb yield with the best results again at 15cm and 20cm.

Four densities were examined: 12, 17, 22 and 27 t/ha. Planting at 22 and 27 t/ha produced the most flowers with the heaviest stems which suggests that where flower production is the priority, the typical planting density of 17 t/ha could be increased. Where multiplication of bulbs stocks is the priority, 17 t/ha at planting is probably optimal.

Three orientations at planting were examined: upright, random and inverted. Orientation had a profound and mostly significant effect on first year flower production with bulbs planted upright producing the most, longest and heaviest stems. Upright produced a small advantage in comparison to random planting and a large advantage in comparison to inverted planting. This advantage was carried through to bulb yield.

These trials assumed that typical grower practice is to plant bulbs at a depth of 15cm, a density of 17 t/ha and using random orientation. The results show that this approach provides perfectly acceptable results across both flower and bulb production as shallower planting and reduced bulb density are likely to depress yield. However, the results also show that slightly deeper planting at higher densities will benefit flower production in particular and for those growers who target flower production rather than bulb production, this would seem to be advantageous.

Gowers have little control over bulb orientation at planting but there has been a belief that bulbs are capable of self-righting within a few months to a year after planting. The results show no evidence for this so growers should not rely on bulbs self-righting to optimise growth on a typical two- or three-year down cycle. However, the lack of a clear benefit to upright planting, in comparison to random, suggests that this is of little concern to growers at the present time and therefore, there is little incentive to develop systems to plant bulbs upright.

Irrigation did not show any effect on either crop. This is not an indication that growers who experience prolonged dry spells, such as on the sandy, free-draining soils of Cambridgeshire, should stop irrigating the crop. However, for growers who only experience episodic lack of rain, irrigation is unlikely to be of benefit.

The lack of any response to fertilisation makes recommendations for fertiliser placement difficult. The fact that no difference between fertilised and unfertilised plots was observed suggests that all treatments had sufficient potassium and sulphur nutrition to support normal growth. Since the response of Narcissus to fertiliser is not an active area of research, this suggests that current practices are probably meeting the needs of the industry.

Bulbs that were warm-stored after HWT showed significant flower damage and severe declines in bulb yield. While warm storage after HWT is not standard practice, growers are advised to exercise vigilance to ensure that boxes of bulbs are correctly processed. If necessary, particularly on large farms, box barcode tracking systems may be used to correctly identify the destination of each box of bulbs at any given stage of handling. Of greater concern is the greater loss in yields of bulbs planted soon after HWT, versus those allowed to dry for longer periods. A precise explanation cannot be inferred from the data, but it is possible that a temperature shock from warm treatment to cold soil may be responsible. With an increasing number of growers planting bulbs directly from HWT (‘still wet’), closer scrutiny of agronomic data is advised to ensure this practice does not harm the crop under real-world conditions.

In many respects, these results are not new but they are a confirmation of existing grower practices. As the Narcissus industry becomes further polarised into bulb and flower production, rather than a combination of both, they do offer growers some evidence on which to change their practices to focus on one or the other.

Knowledge exchange

A number of different KE events and activities were undertaken, including:

- University of Warwick Postgraduate Student Symposium (March 2015)
- AHDB Precision Agriculture conference (March 2015)
- Spalding Flower Festival (April 2015)
- AHDB studentship conference (2015)
- University of Warwick Postgraduate Student Symposium (March 2016)
- Narcissus Grower Groups in Cornwall and Lincolnshire (May 2016)
- Narcissus Grower Groups in Cornwall and Lincolnshire (May 2017)

Action Points

- In-box post-HWT fungicidal foam appears to be a promising innovation that might replace, or supplement, the use of fungicides in HWT. It is recommended to carry out a comparison of approaches to compare the efficacy of different approaches and products.
- The use of controlled atmospheric storage to control pests (nematodes, mites and bulb fly) should be investigated. Reduced oxygen conditions might provide a clean and dry alternative to HWT.

