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The effect of plant density and plant arrangement on yield, bulb maturity and 'thick-necking' in onion (*Allium cepa* L.)

*Indflydelsen af plantetæthed og vokserummets udformning på udbytte, modenhed og forekomsten af halsløg i løg (*Allium cepa *L.)*

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Summary

From 1985 to 1987 a high-yielding hybrid cultivar of onion (*Allium cepa* L.) was grown in different bed systems at the Department of Vegetables, Årslev.

Different plant densities and spatial arrangements were established by sowing seeds in four row distances (45, 30, 22.5 and 15 cm) and three seeding rates (20, 30 and 40 seeds/m row).

The total marketable yield increased with increasing plant density reaching a maximum of 51.8 t/ha in the bed system with a 15 cm row distance and 40 seeds/m row (185 plants/m^2 at emergence). The yield of bulbs of the large size gradings tended to increase when plant spacing approached a quadratic arrangement.

An average of 18% of total yield of bulbs were thick-necked i.e. scallions. Increasing plant density enhanced bulb maturity (harvest) and reduced the proportion of thick-necked onions in years where the climatic conditions promoted incomplete bulb development.

Key words: Bed growing, bulb size, plant spacing, rectangularity, scallion.

Resumé

I perioden 1985-1987 blev en højtydende hybridsort af løg (*Allium cepa* L.) dyrket i forskellige bedsystemer ved Afdeling for Grønsager, Årslev.

Forskellige plantetætheder og former for vokserum blev etableret ved at så frø på fire rækkeafstande (45, 30, 22.5 og 15 cm) og tre udsædsmængder (20, 30 og 40 frø/m række).

Det totale salgbare udbytte steg ved stigende plantetæthed og nåede et maksimum ved 51,8 t/ha i bedsystemet med 15 cm's rækkeafstand og 40 frø/m række (185 planter/m^2 ved fremspiring). Udbyttet af løg i den store størrelsesfordeling syntes at stige, når vokserummet blev tilnærmelsesvis kvadratisk.

I gennemsnit af alle høstede løg var 18 pct. halsløg. Stigende plantetæthed fremskyndede modenhed og reducerede andelen af halsløg i år, hvor de klimatiske forhold gav anledning til ufuldstændig løgudvikling.

Nøgleord: Beddyrkning, løgstørrelse, rektangularitet.

Introduction

Previous investigations have shown that plant spacing influences total yield of onion bulbs and their size grading (1, 5, 7, 8).

The yield of marketable bulbs increased with increasing plant density at 60, 45 and 30 cm row distance (8).

Reducing row distance from 46 cm to 23-30 cm at an specific plant density (75 plants/m^2) resulted in an increase of total yield by 10-30% (1). The effect was greatest with high plant densities. Generally yield increased when plant arrangements approached a quadratic arrangement (1, 5).

Optimum plant density and plant arrangement vary according to the purpose of onions. Bulbs of the size grading 4-6 cm are preferred for fresh consumption. For industrial use bulbs greater than 6 cm are preferred (8).

Investigations on the size grade distribution (7) have shown that by spacing plants more equidistant to each other (i.e. both inter-row and intra-row) the total yield increase was mainly due to increasing bulb yield in the larger size grading. Effects of plant arrangement and plant density are often confounded, therefore it is important to examine their separate and interactive effects on onion development, yield and bulb size.

Plant density and plant arrangement also influenced bulb maturity. When plant density increased the number of days prior to harvest were decreased (7). A late maturity date was associated with a higher proportion of onions with incomplete bulb development (2). Bulbs fail to mature and continue leaf blade production into the autumn. They have thick pseudostems and a low ratio of bulb to neck diameter and are called 'thick-necked' onions i.e. scallions. These thick pseudostems cannot be satisfactorily dried and may cause rot in storage.

In Denmark onions are normally grown in double-rows 45-50 cm apart and 5 cm between the single rows. Growing onions at an approximate quadratic plant arrangement implies sowing/planting in a bed-system with fixed wheelings between each bed. Weeds need to be controlled chemically.

This investigation was carried out to examine the effect of plant density and plant arrangement on yield, bulb maturity and 'thick-necking' in a high-yielding hybrid cultivar of onions.

Materials and methods

In a field experiment onion (*Allium cepa* L.) was grown at varying plant spacings. The trial was carried out over a three year period from 1985 to 1987 at the Department of Vegetables, Årslev, on a sandy loam soil.

To allow different plant densities and plant arrangements the onions were grown in a bed system. The bed consisted of 3, 4, 5 or 7 rows with 45, 30, 22.5 or 15 cm distances respectively. The width of the bed was 1.5 m with 90 cm from outerrow to outerrow and 60 cm fixed wheelings. The length of the bed was 10 m. Plot size for harvest was 1.5 × 8 m.

The experimental factors were two levels of nitrogen fertilizer (100 and 140 kg N/ha), four different row distances and three seeding rates (20, 30 and 40 seeds/m row). The design was a systematic block, split plot design with 2 replicates. The nitrogen fertilizer level was main plot, row distance and seeding rate were sub plots. Table 1 shows the intended plant stands/m^2 in the bed at 75% emergence. Rectangularity (r) at each combination of row distance and seeding rate was calculated. Rectangularity (r) is defined as the ratio of the interrow (between-row) to intrarow (within-row) distances. Guard plots (10 m × 1.5 m) were established between the main plots. In the guard plots 50 seeds/m row were sown in double rows at 45 cm row distance.

Pelleted seeds were sown in single rows with a Stanhay precision drill. The sowing dates were 26 April 1985, 18 April 1986 and 27 April 1987. In 1985 the cultivar 'Hyduro F1' and in 1986 and 1987 the cultivar 'Hyper F1' was grown.

Disease and pests were controlled as recommended to obtain optimum plant growth. Weeds were controlled by herbicides before emergence. Post emergence weeding was carried out by hand.

Preplant fertilizer (30 kg N/ha) was applied before sowing and supplementary nitrogen fertilizer (70 or 110 kg N/ha) was applied at the end of May or the beginning of June.

Plant stand was recorded for 1 m^2 of each plot immediately after emergence and again just before harvest at the same place.

Crop maturity was defined as the stage where 80% or more plants had softened pseudostems and as a consequence the crop foliage canopy collapsed. The per cent foliar fall over was recorded at 3-day intervals. The onions were harvested at 80-90% foliar fall over and windrowed in the

Table 1. Experimental design. Row distance, seeding rate, intended number of plants/m^2 in the bed at 75% germination and rectangularity (r).
Forsøgsdesign. Rækkeafstand, udsædsmængde, tilstræbt antal planter/m^2 i bedet ved 75 pct. markspiring og rektangularitet (r).

Row distance *Rækkeafstand*		Seeding rate *Udsædsmængde*		
		20 seeds per m row *20 frø pr. m række*	30 seeds per m row *30 frø pr. m række*	40 seeds per m row *40 frø pr. m række*
45 cm	Plants per m^2			
(3 rows in the bed system)	*Planter pr. m^2*	33	50	67
(3 rækker i bedsystemet)	r	9.0	13.5	18.0
30 cm	Plants per m^2	50	75	100
(4 rows in the bed system)	r	6.0	9.0	12.0
22.5 cm	Plants per m^2	67	100	133
(5 rows in the bed system)	r	4.5	6.8	9.0
15 cm	Plants per m^2	100	150	200
(7 rows in the bed system)	r	3.0	4.5	6.0

Nitrogen fertilizer levels: 100 and 140 kg N/ha.
Kvælstofgødningsniveau: 100 og 140 kg N/ha.

field. After 10-14 days the plants were dried artificially at 20-25° C in a ventilated store. The dried leaves were removed and the bulbs were sorted into marketable, thick-necked, diseased and bolted onions. The class 'diseased' also contained cracked bulbs. In 1985 and 1986 total yield of outerrows were recorded separately. The marketable onions were sorted into seven size gradings increasing in diameter from 2 to 8 by steps of 1 cm. Bulbs <2 cm were not registered. The total weight and number of bulbs in each grading were recorded. The dry matter content was also determined.

Climatic conditions

Growing spring-sown onions in Denmark is at a northern borderline and a relatively high temperature during the growing season is crucial for bulb development. In Fig. 1 the monthly average temperature from April to November is shown for the years 1985-87 in comparison to the average for 1931-1960.

In 1985 there was a cool period at sowing and the temperature was almost 1° C below average during the growing period except in May. In 1986 early summer temperatures were close to normal but late summer and autumn were cool. In 1987 temperature around sowing was relatively high but during early summer the temperature was remarkably below average.

Precipitation was below average in 1985 and 1986, and irrigation was carried out. In 1987 no irrigation took place.

Statistical methods

Data are presented on a fresh weight basis and are means of three years. Analysis of variance for a split plot design were performed on each variable using the Statistical Analysis System (SAS Institute Inc., 1987). The main effects row distance, seeding rate and nitrogen level and their two and three way interactions were tested using General Linear Models procedure. The denominator in the F-test was the interaction between the effect

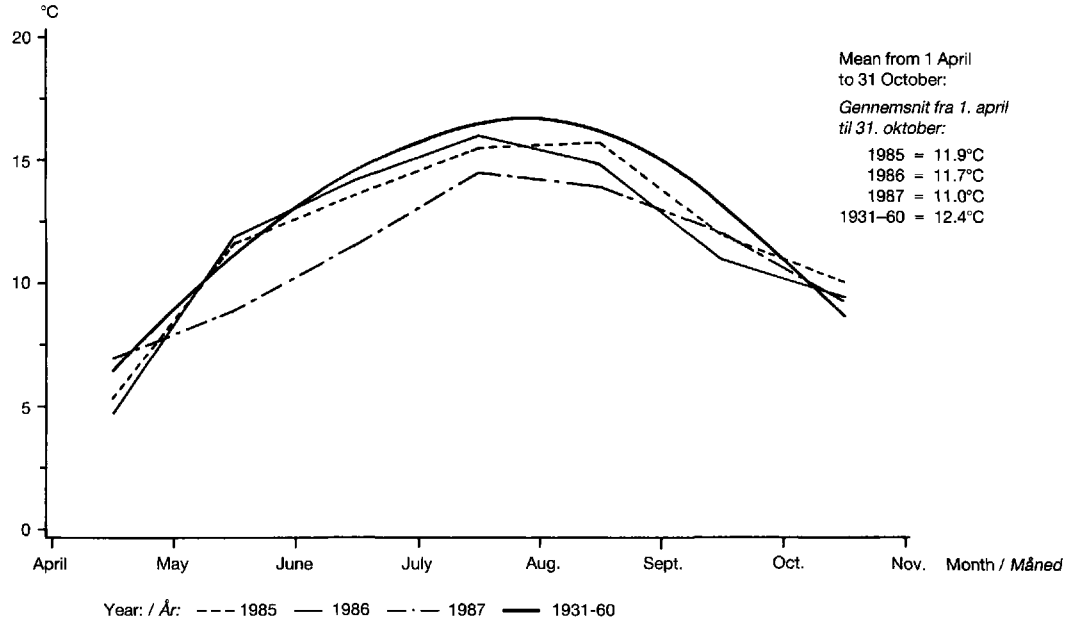

Fig. 1. Temperature (°C). Monthly mean from 1 April til 31 October in 1985-87 at Årslev and the average for 1931–1960.
Temperatur (°C). Månedlig middel fra 1. april til 31. oktober i 1985-87 ved Årslev og gennemsnit for 1931-60.

in question and year. Means of main effects were separated by a test for least significant difference (LSD) with a significance level of 5%.

Results

Plant stand

Sample counts immediately after emergence showed only small discrepancies from the target population. In 1985 the emergence rate was low whereas in 1986 and 1987 the obtained plant stands were sligthly higher than intended. Emergence rate was 66% on the average for the three years. Sample counts at maturity showed that plant densities were slightly lower than those recorded at emergence. The reduction of plants/m^2 was found to be proportional to plant density. The average plant stand was reduced by 8% during the growing season. However the total number of bulbs harvested was somewhat lower especially at high plant densities (Table 2) probably due to onions <2 cm.

Yield and other data were considered for the plant stand at emergence.

Yield

Since no significant effect of nitrogen was found, the following results are an average of the two nitrogen levels.

As shown in Table 2 the total weight of bulbs increased with increasing plant density ranging from 30.0 t/ha to 54.1 t/ha. There was no significant interaction between row distance and seeding rate. Total yield was the highest at the lowest row distance ($P < 0.01$) and with the highest seeding rate ($P < 0.05$).

The yield of marketable onions ranges from 25.0 t/ha to 51.8 t/ha also increasing with increasing plant density. It was significantly influenced by row distance ($P < 0.01$) and seeding rate ($P < 0.01$). The highest yield was found at 15 cm or 22.5 cm row distance and 40 seeds/m row. The yield of unmarketable onions averaged 4.0 t/ha being the highest at low plant densities.

Table 2. Emergence (plants/m^2 in the bed), total number of bulbs harvested (1000/ha), total yield (t/ha), total marketable yield (t/ha), marketable yield (t/ha) in the size gradings 2-4 cm, 4-6 cm, 6-8 cm and >8 cm and mean marketable bulb weight (g) at each combination of row distance and seed rate.
Fremspiring (planter/m^2 i bedet), total antal høstede løg (1000/ha), total udbytte (t/ha), salgbart udbytte (t/ha), salgbart udbytte (t/ha) i størrelsessorteringerne 2-4 cm, 4-6 cm, 6-8 cm og >8 cm og gennemsnitlig løgvægt (g) salgbar ved hver kombination af rækkeafstand og udsædsmængde.

Row distance (cm) *Række-afstand (cm)*	Seed rate (seeds/ m row) *Udsæds-mængde (frø/m række)*	Emergence (plants/ m^2) *Frem-spiring (planter /m^2)*	Total *Total* Number (1000/ha) *Antal (1000 pl./ha)*	Yield (t/ha) *Udbytte (t/ha)*	Total marke-table (t/ha) *Total salgbare (t/ha)*	Marketable yield(t/ha) of bulb size *Salgbart udbytte i størrelsessorteringerne* 2-4 cm	4-6 cm	6-8 cm	>8 cm	Mean market-able weight (g) *Gennem-snitlig løgvægt (salgbare)*
45	20	26	219	30.0	25.0	0.1	3.6	11.5	9.8	181
45	30	43	336	37.1	32.4	0.5	7.2	19.6	5.1	140
45	40	61	489	43.9	40.2	1.2	13.3	23.9	1.7	112
30	20	43	304	35.7	29.8	0.2	5.3	16.1	8.2	155
30	30	67	472	45.5	41.1	1.1	12.6	23.9	3.5	117
30	40	90	670	50.3	46.2	2.7	21.5	21.3	0.7	97
22.5	20	55	361	39.8	34.6	0.4	7.5	21.3	5.5	139
22.5	30	91	607	49.3	45.6	1.9	17.8	24.8	1.2	101
22.5	40	119	793	54.3	51.6	4.6	26.7	20.0	0.3	85
15	20	92	551	48.3	44.9	1.4	15.7	26.0	1.8	106
15	30	134	842	53.5	50.4	4.9	27.1	18.1	0.4	81
15	40	185	1162	54.1	51.8	10.2	33.7	7.7	0.1	64
Average *Gennemsnit*										
45			348	37.0	32.5	0.6	8.0	18.3	5.5	144
30			482	43.8	39.0	1.3	13.1	20.4	3.1	123
22.5			587	47.8	43.9	2.3	17.3	22.0	2.3	108
15			852	52.0	49.0	5.5	25.5	17.3	0.8	86
LSD row distance *rækkeafstand*			85	0.6	0.9	0.4	1.0	1.0	0.5	26
	20		359	38.5	33.6	0.5	8.0	18.7	6.3	145
	30		564	46.4	42.4	2.1	16.2	21.6	2.6	110
	40		779	50.7	47.5	4.7	23.8	18.2	0.7	90
LSD seed rate *udsædsmængde*			106	0.8	0.9	0.4	1.2	1.3	0.7	34

The marketable yield in the commercial size gradings shifted to the smaller size classes when plant density increased and mean bulb weight decreased from 181 g to 64 g.

There was no significant effect of row distance or seeding rate on the dry matter content which was 11.3% on average.

In 1985 and 1986 outerrows were higher yielding than innerrows. On average total yield was 14, 22 and 28% higher in outerrows at 30, 22.5 and 15 cm row distance respectively.

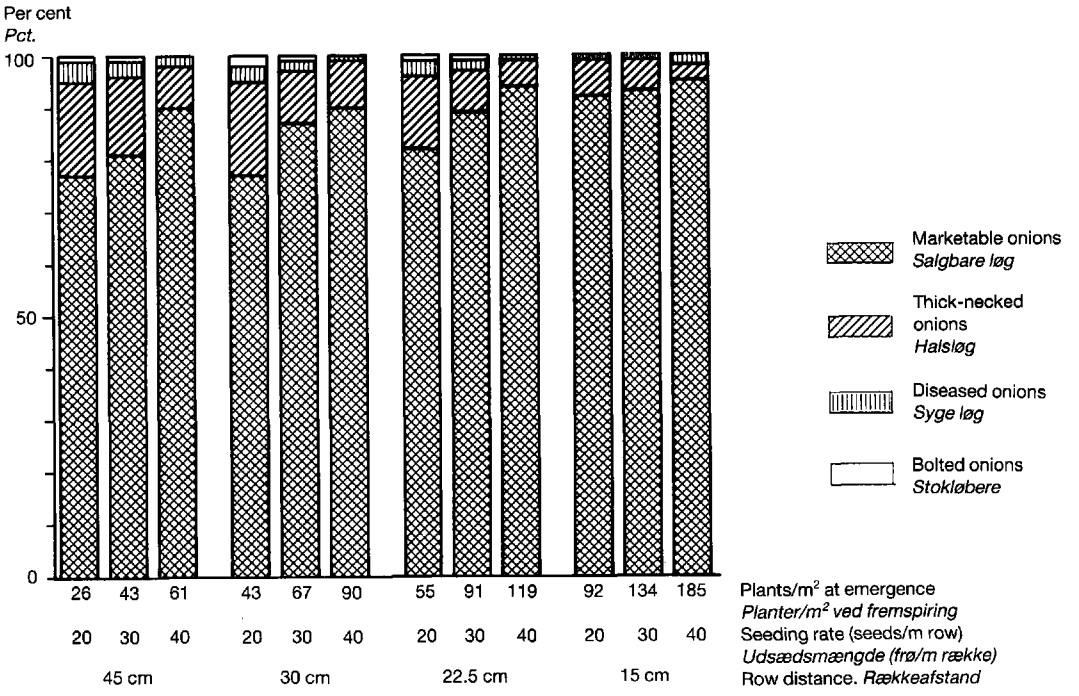

Fig. 2. Distribution of onions in per cent of total yield in marketable, thick-necked, diseased and bolted onions at each combination of row distance and seeding rate.
Fordeling af løg i procent af total udbytte af salgbare løg, halsløg, syge løg og stokløbere ved hver kombination af rækkeafstand og udsædsmængde.

Distribution of bulbs

Fig. 2 shows the distribution of marketable, thick-necked, diseased and bolted onions in per cent of total yield at each combination of row distance and seeding rate. An average of 10% of the total yield was thick-necked onions with the highest proportion at the lowest plant densities. The degree of thick-necked onions varied within year (see »Thick-necked onions«).

The percentage of diseased onions was also highest at low plant densities with a maximum of 4% of total yield. In 1987 some downy mildew, *Peronospora destructor,* was observed, but in general there were no serious problems concerning disease. There were only very few bolted onions.

Bulb size

Fig. 3 shows the size grade distribution by yield (t/ha) for selected combinations of density and rectangularity (r). The combinations are selected to show the greatest variability in plant density and the rectangularity (r) within these. A range of onion sizes was produced and as density increased there was a shift to smaller grades.

Table 3 shows that increasing plant density from 67 to 100 intended plants/m^2 *at the lowest rectangularity* (r) decreased the weight of bulbs >8 cm by 68% (3.7 t/ha). While bulbs in the grades 2-4 cm, 4-6 cm and 6-8 cm all increased.

Increasing the density from 67 to 100 intended plants/m^2 *at the highest rectangularity* (r) decreased the weigth of bulbs >8 cm by 59% (1.0 t/ha) and bulbs at 6-8 cm by 11% (2.7 t/ha). While bulbs at 4-6 cm increased by 61% (8.2 t/ha) and those at 2-4 cm by 121% (1.5 t/ha).

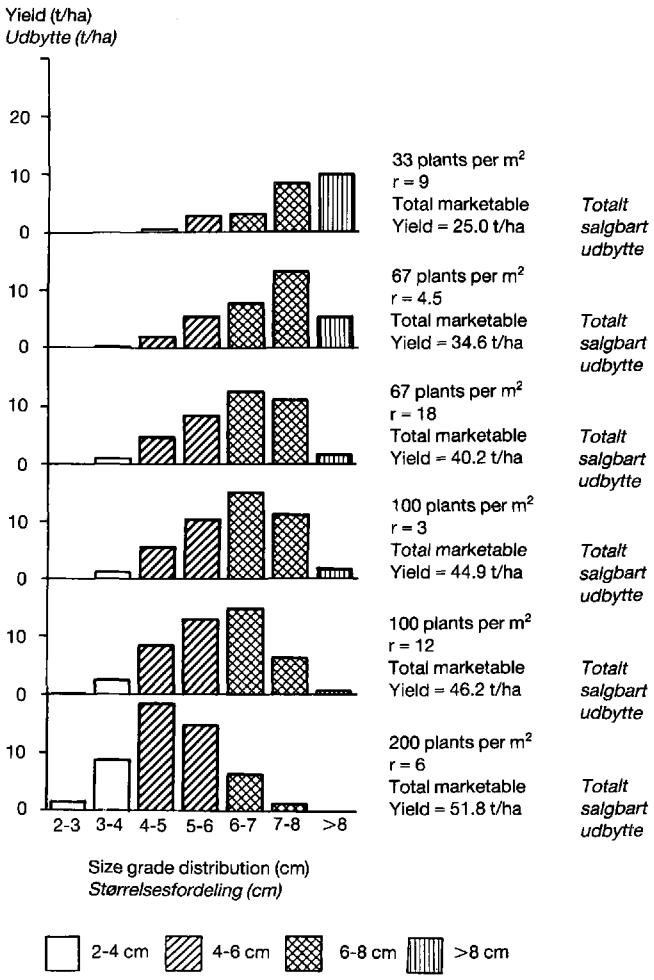

Fig. 3. The influence of plant density (intended plants/m^2) and rectangularity (r) on the size grade distribution and total marketable yield.

Plantetæthedens (tilstræbt antal planter/m^2) og rektangularitetens (r) indflydelse på størrelsesfordelingen og totalt salgbart udbytte.

At the same plant density increasing rectangularity (r) tended to produce bulbs of smaller size grade. Reducing the rectangularity (r) from 12.0 to 3.0 at the intended plant stand 100 plants/m^2 the yield of onions >8 cm increased by 149% (1.1 t/ha) whereas the yield of onions between 4-6 cm decreased. These changes were not significantly different neither was total yield.

Foliar fall over and maturity

Fig. 4 shows the per cent foliar fall over when the first mature plots were harvested. The extent of foliar fall over was influenced by row distance and seeding rate with bulbs grown at high plant densities maturing earlier. Interaction between row distance and seeding rate was significant ($P < 0.001$). The effect of row distance was higher at high seeding rates.

Table 3. The influence of rectangularity (r) on total marketable yield (t/ha) and marketable yield (t/ha) in the common size gradings 2-4 cm, 4-6 cm, 6-8 cm and >8 cm at the intended plant densities 67-75 plants/m^2 and 100 plants/m^2.
Rektangularitetens (r) indflydelse på total salgbare udbytte (t/ha) og salgbare udbytte (t/ha) i de almindelige størelsessorteringer 2-4 cm, 4-6 cm, 6-8 cm og >8 cm ved de tilstræbte plantetætheder 67-75 planter/m^2 og 100 planter/m^2.

Intended plant density (plants/m^2) *Tilstræbt plantetæthed (planter/m^2)*	Actual plant density (plants/m^2) *Aktuel plantetæthed (planter/m^2)*	Rectangularity (r) *Rektangularitet*	Marketable yield (t/ha) *Salgbare udbytte (t/ha)*				
			2-4 cm	4-6 cm	6-8 cm	>8 cm	Total
67	55	4.5	0.4	7.5	21.3	5.5	34.6
75	67	9.0	1.1	12.6	23.9	3.5	41.1
67	61	18.0	1.2	13.3	24.0	1.7	40.2
LSD			–	4.3	–	–	–
			n.s.	*	n.s.	n.s.	n.s.
100	92	3.0	1.4	15.7	26.0	1.8	44.9
100	91	6.8	1.9	17.8	24.8	1.2	45.6
100	90	12.0	2.7	21.5	21.3	0.7	46.2
LSD	–		–	–	–	–	–
	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.

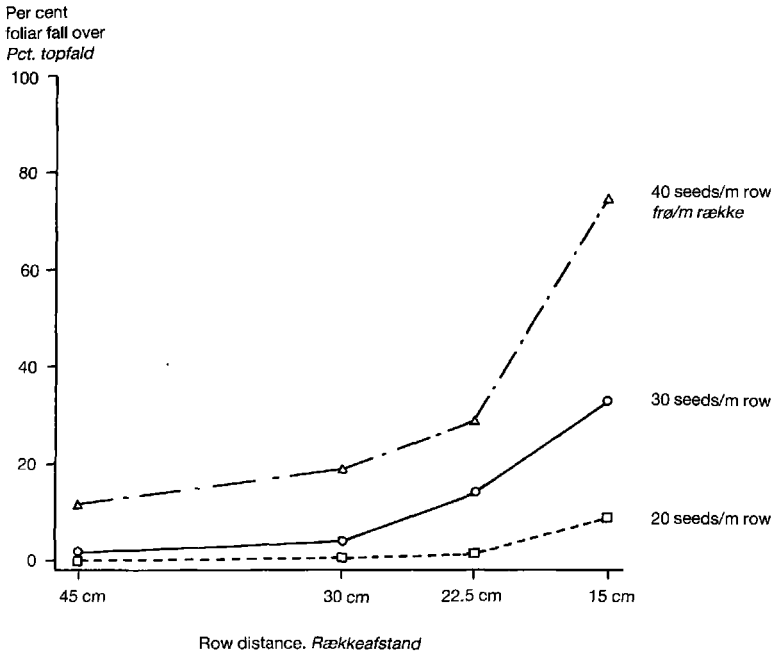

Fig. 4. The influence of row distance and seeding rate on the per cent foliar fall over.
Rækkeafstandens og udsædsmængdens indflydelse på procent topfald.

In 1985 and 1987 several plots of onions had not reached maturity by the end of the growing season (beginning of October) and were harvested before 80-90% foliar fall over to avoid quality deterioration. The duration of the harvest period was 10 and 9 days respectively. In 1987 there was a serious attack by *Peronospora destructor* which enhanced foliar collapse.

In 1986 almost all onions had reached maturity by the end of the growing season. The harvest period was from 8 September to 10 October. Plants at high densities were harvested 32 days earlier than plants at low densities. Increasing row distance from 15 cm to 45 cm delayed harvest by 17 days. Decreasing seeding rate from 40 seeds/m row to 20 seeds/m row delayed harvest by 18 days.

At the same plant density the foliar fall over increased with increasing rectangularity (r), but the effect was not significant.

Thick-necked onions

The occurrence of thick-necked bulbs, i.e. scallions, was rather high especially after the cool summers of 1985 and 1987, but in 1986 hardly any thick-necked onions occurred (2% of the total number of plants). In 1987, 36% of the harvested plants were thick-necked, which was equivalent to 5.6 t of the total harvested yield of 29.6 t/ha.

As illustrated in Fig. 2 and 5 the incidence of thick-necking is strongly influenced by row distance and seeding rate being greatest at low plant densities. At the lowest plant density (26 plants/m^2) up to 18% of total yield and 32% of all bulbs were thick-necked. The interaction between row distance and seeding rate on the percentage of thick-necked onions was significant ($P < 0.05$). The effect of row distance was higher at low seeding rates.

Nitrogen level had some effect on the percentage of total number of thick-necked onions,

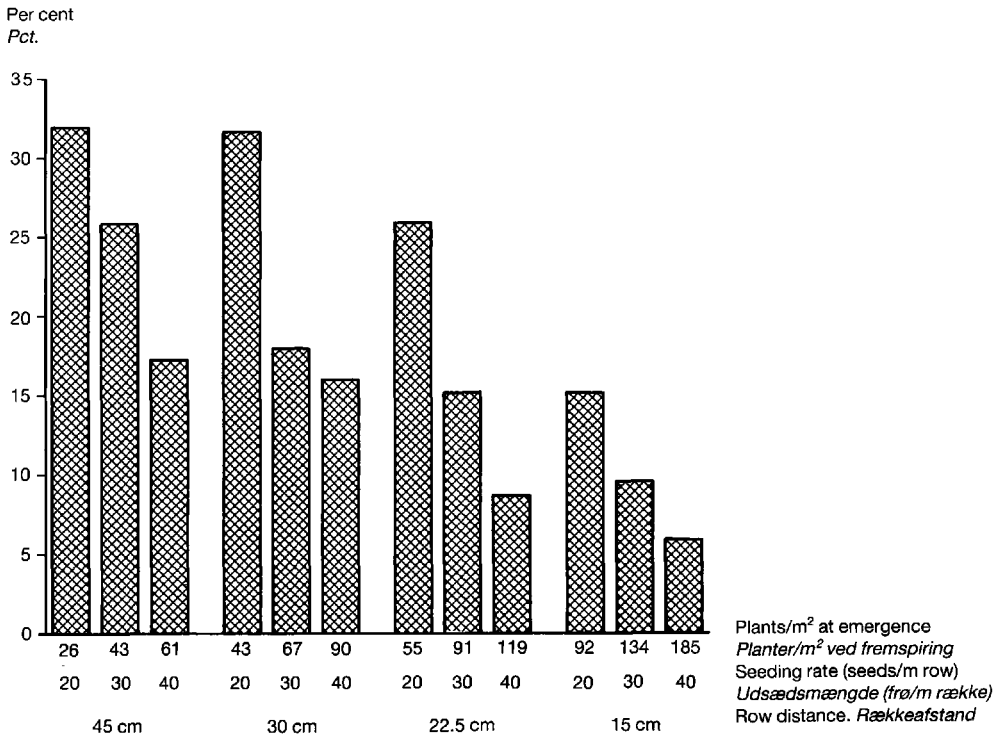

Fig. 5. The influence of row distance and seeding rate on yield of thick-necked onions in per cent of total number of bulbs harvested.

Rækkeafstandens og udsædsmængdens indflydelse på udbytte af halsløg i procent af det totale antal høstede løg.

which was 20.1% when 140 kg N/ha was applied compared to 16.8% when 100 kg N/ha was applied. The effect however was not significant.

Decreasing rectangularity (r) tended to decrease the proportion of thick-necked onions.

Discussion and conclusion

The total yield of marketable bulbs increased by increasing plant density. There was no apparent effect of nitrogen level on total yield which indicates that the nutrient supply had not been minimizing yield even at the highest plant densities. In a previous investigation the optimum fertilizer level was 120 kg N/ha when growing 80 plants/m^2 (9) but yield level was higher.

The relationship between plant density and total yield of bulbs seemed to approach an asymptotic curve (4, 5). Differences in total yield were not detected when plant densities increased from 119 to 185 plants/m^2.

In general the yield of marketable bulbs increased by increasing plant density but the size grade distribution shifted towards smaller size bulbs. A suitable size grade distribution of onions destined for the fresh market is 2/3 bulbs in the grade 4-6 cm and 1/3 bulbs in the grade 6-8 cm. This was obtained at the highest plant density (185 plants/m^2 at emergence) which in this experiment was the maximum yielding capacity. For industrial use onions >6 cm are preferred. The highest yield of large onions was found at plant densities ranging from 40 to 90 plants/m^2.

Bulb formation is induced by long days and enhanced by relatively high temperatures (10). After two cool summers in 1985 and 1987 the proportion of immature and thick-necked onions was high. This is in agreement with the findings (2), which stated that earlier maturity appears to be associated with higher surface soil temperatures in the spring and with more rapid seedling growth in the early part of the year.

Increasing nitrogen level slightly delayed bulb development and increased the number of thick-necked onions. However the effect was not significant perhaps due to insufficient estimation of the main effects in split plot design.

Plant density had a pronounced effect on bulb maturity and the incidence of thick-necking. At high plant densities maturity was hastened up to 17 days and the proportion of thick-necked plants was remarkably lower. This is in agreement with earlier findings (3, 11).

At increasing plant density leaf area index will increase which means that at the beginning of the season crop growth is faster at higher plant densities but later it results in greater mutual plant shading (13). As irradiance passes through a leaf canopy the ratio of red to far red light decreases which promotes bulb initiation (12) i.e. promotes foliar fall over and reduces the incidence of thick-necked plants.

Onion plants intercept a low per cent of the incident radiation and have a high interplant competition for light. Any gains from spatial arrangement, i.e. decreasing rectangularity (r) will improve light interception and reduce interrow competition.

However no total yield increase was found in this experiment by decreasing rectangularity (r) at a given plant density. Though a more extensive test with a wider range of densities might show an interaction. In this experiment seeds were sown directly which might have resulted in some variation in the spatial arrangement compared to planting. Furthermore during plant growth plant stands were reduced by 8%. Therefore one can not assume that the intended rectangularity is kept through the growing season.

Increasing rectangularity (r) tended to advance maturity and to decrease the number of thick-necked plants. This was probably due to higher light competition in the rows and mutual shading, but the differences were not significant.

When onions are grown in beds of 1.5 m with fixed wheelings the area is not optimally utilized. The outerrows compensated by producing up to 29% more than the innerrows at the low row distance because of the wider space on one side of them. However plants in the outerrows are not considered to be able to exploit the whole wheeling area. Therefore, the edgeeffect might not fully compensate the area reduction.

When using a bed system soil compaction is restricted to the fixed wheelings. Soil compaction reduces emergence rate and increases the number of thick-necked plants (6) and thereby influences yield and quality.

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