Plant density effect on oil seed yield and quality of industrial hemp cv. Fasamo in Canterbury

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Abstract
Industrial hemp (*Cannabis sativa*) is an ancient crop. The majority of hemp production has been for fibre, but more recently interest in the use of hemp seed oil has developed. The German-bred monoecious dual-purpose cultivar 'Fasamo' was trialled over two years in Canterbury to determine the optimum plant population for oilseed production. Target populations were 125, 150, 175, 200, 225 and 250 plants/m^2. Actual established populations ranged from 124 to 346 plants/m^2. In 2006-07, yields ranged from 804 kg/ha to 931 kg/ha, with a positive linear trend of 0.823 kg/ha yield gain for every extra plant/m^2 established. Economic return ranged from $3,482 to $3,838/ha, with a non-significant positive linear trend of $2.44 nett gain for every extra plant/m^2 established. In 2007-08 yields were much higher, ranging from 1,640 to 1,849 kg/ha producing an economic return of $7,183 to $8,092/ha. However, there was no significant linear trend found between established plant density and either yield or economic return. Oil quality did not appear to be affected by differing plant populations. Agronomic management and climatic conditions during production appeared to have a greater impact on yield and economic return than plant population. Considering both practical and quantitative factors, a target plant population of 150-225 plants/m^2 is recommended for Fasamo oilseed production in Canterbury depending on site yield potential.
Keywords: *Cannabis sativa*, oil content, plant population, economic return, essential fatty acids, α-linolenic acid, γ-linolenic acid, linoleic acid, oleic acid

Introduction

Industrial hemp (*Cannabis sativa* L.) has been grown around the world for centuries. Its avid followers suggest that it is close to the perfect crop (Roulac 1997; Benhaim 2003). End-uses appear limitless, and include fibre in rope, clothing, paper, textiles, insulation, plastic, biofuel, organic mulch and animal bedding (Roulac 1997; Bourie 2003). Seed can be used for human or animal consumption and may be consumed as whole seeds, flour, protein, ice cream and milk (Benhaim 2003). Oil extracted from seeds is suitable for human consumption and industrial uses, such as in the inclusion of cosmetics (Benhaim 2003; Bourrie 2003). Hemp oil fatty acid content approaches the optimal 3:1 balance of essential fatty acids linoleic acid: α-linolenic acid and is reportedly unique among the common plant oils (Ranalli 1999). However, the production of hemp and the consumption of hemp products are not legal in all countries (Benhaim 2003).

Industrial hemp is grown on a range of soil types and under varied climatic conditions, primarily for fibre production. It is a frost sensitive, spring planted annual that grows well under temperate conditions (Kelly & George 1998). Rapid growth is achieved on well-drained, fertile, medium-heavy soils (Ranalli 1999). The crop should be established in a well worked seed-bed free of compaction. Crops can be planted with most drill types that produce 12-20 cm rows. Plants are naturally dioecious but breeding programs in Europe have concentrated on producing monoescious types (Bocsa & Karus 1998). Once established plants grow rapidly and provide effective weed suppression. Fertiliser trials are not well documented, but crops are often treated the same as wheat (Ranalli 1999). Plants can range from 1-8 m tall, with strong stems and are wind pollinated. Most breeding programs focus on fibre production and quality, with seed yield being of secondary importance (Bocsa 1999).

McIntosh *et al*. (1998) suggests hemp seed was first imported into New Zealand (NZ) in 1892, but a fibre industry failed to establish. The rebirth of commercial production of industrial hemp commenced in 2001 in NZ, when government legislation banning the growing of this crop was modified (McPartland *et al*. 2004). Current production is limited by strict and costly licensing laws with respect to growing, handling and selling of hemp products within New Zealand. Almost all hemp cultivars are known to produce the narcotic compound delta-9-tetrahydrocannabinol (THC). Drug type varieties contain between 2-56% THC and low levels of cannabidiol (West 1998). Only cultivars on the NZ National Approved List that produce THC levels of <0.3% are permitted to be grown (Ministry of Health 2008). In addition, only the oil extracted from seed is allowed to be sold for human consumption (New Zealand Food Safety Authority 2008), the rest of the plant can be sold only as livestock feed. Established crops must have foliage samples submitted for THC testing prior to the end of flowering and results provided to NZ governmental health authorities (McPartland *et al*. 2004).

Since 2001 both Midlands Seed Ltd and Plant Research (NZ) Ltd have been working to develop best management practices for oilseed hemp production in Canterbury (Plant Research (NZ) Ltd 2002). This work has resulted in the selection and registration of a German-bred, dual-purpose, monoecious cultivar, 'Fasamo'. Hemp crops around the world are grown at a wide range of densities depending on the environment, cultivar and end use. However, scientific publications on this topic are limited. Plant density is known to affect the time to full light interception, the degree of branching, thickness of stems, and also plant height (Ranalli 1999). Most previous research has been conducted with an emphasis on fibre production, where wide-ranging populations of anywhere between 30-500 plants/m^2 are commonly recommended (Bocsa & Karus 1998; Ranalli 1999; Amaducci *et al*. 2005). Bocsa and Karus (1998) recommend 125-150 plants/m^2 for oilseed production in Europe when sowing in 20 cm rows. Work reviewed by McPartland *et al.* (2004) mentions seed yields in preliminary NZ trials peaking at 90-120 plants/m^2 for a number of cultivars, including Fasamo.

The aim of this study was to determine the optimum plant population for oilseed production and economic return for Fasamo hemp. The impact of plant density on seed yield and oil quality was also examined.

Methods

One trial site was established each year for two years. In 2006-07 a trial at Ashburton consisting of three replicates of six target plant populations was established on 10 October 2006 and harvested on 6 March 2007. This trial was on a Lismore stony silt loam soil (Kear *et al*. 1967) and the site had border dyke irrigation. In 2007-08 a trial at Methven consisting of four replicates with the same target populations was established on 2 November 2007 and harvested on 28 February 2008. This site was on a mixture of Mayfield shallow silt loam and Hororata stony silt loam series (Kear *et al*. 1967). The site had Rotorainer irrigation. The later planting date for site 2 was due to the fact that this site was at a significantly higher altitude and therefore more prone to late frosts than site 1, the latter being near sea-level.

Target populations were: 125, 150, 175, 200, 225 and 250 plants/m^2, which were arranged in a randomised complete block design at both sites. The sample size used for sowing was adjusted to take account of different germination percentages and thousand seed weights of the two seed lots used in the two trials. All plots were 1.2 m wide, made up of eight rows at 0.15 m between row spacings. Total plot area ranged from 10-15 m^2. At both sites, untreated cv. 'Fasamo' stock seed was sown without fertiliser using an Ojyord cone-seeder drill. All trial sites were situated within commercial fields of hemp to help reduce bird damage at maturity. Gas operated bird scarers were also placed within trials near harvest time. No bird damage was observed.

Established plant populations were estimated when plants had 3-6 pairs of leaves; four samples of 0.25 m^2 were counted per plot. No weed or pest control was applied. In 2006, plots received a broadcast application of 250 kg/ha Cropmaster 15 (15:10:10:8) applied by hand when the crop was approx 50 cm tall. This site also received varying amounts of effluent in irrigation water (border dyke) during the growing season (full analysis not available). The Methven site received 150 kg/ha Cropmaster 15 (15:10:10:8) pre-plant incorporated and then 125 kg/ha Urea (46:0:0:0) one month after planting. Both sites were irrigated with the decision of application timing and amount being made by the commercial growers. No records of irrigation were made.

The entire plot was harvested by hand when 80% of the seed had changed to a grey-brown colour and the first signs of seed shedding were observed. In 2006-2007 all seedheads were cut and allowed to air dry in bird-proof sheds for several days before threshing with a Wintersteiger Elite plot combine. In 2007-2008 seedheads were threshed immediately after cutting. Seed for both harvest seasons was dried for 48 hrs at 40ºC and then dressed using a Rotational Kornservice SLN seed cleaner with a 0.5 mm slotted riddle on the bottom and a round 2 mm sieve on the top. The machine dressed (MD) sample was weighed and the moisture content (MC) determined using a Precisa XM60 Moisture Analyser set at 125ºC. Final yields were corrected to 8% MC.

Seed from the 2006-07 trial only was analysed for oil content (991.36, AOAC 2002) by AgriQuality Ltd (now AsureQuality Ltd), New Zealand. Samples from each plot were bulked across the plots for each treatment for chemical analysis purposes. The fatty acid profile was determined using an in-house method adapted from (Bannon *et al.* 1985). Fatty acids are reported as a percentage of total fatty acids.

Analysis of variance of seed yield and economic return for yield with increasing plant populations was performed as described by Saville (1983) in Genstat 11. Polynomial contrasts were included to look for trends in yield and return with increasing target plant populations.

Economic return was calculated using the following formula:

Economic Return ($/ha) = {($4.55/kg x yield kg/ha) – ($8.00/kg x seeding rate kg/ha)}

The $4.55 return to the grower which is calculated as follows: the contract price is assumed to be $5.00/kg of machine dressed seed dried to 8% MC. However, for each kg of wet field dressed (FD) seed, cost of cartage is $0.03/kg and cost of drying to 8% MC (from an assumed average of 20% MC) is $0.16/kg wet weight. After drying, the original kg now weighs 870g dry FD. Cost of dressing is $0.14 for the 870g, assuming the cost of dressing is $0.16/kg at 8% MC FD. Assuming a 15% loss with dressing, the final weight is 740g of MD seed at 8% MC. Costs were 0.03 + 0.16 + 0.14 = $0.33 for this 740g, which scales up to $0.45/kg of MD seed at 8% MC. Hence the net price to the grower is $5.00 – $0.45 = $4.55. Cost of stock seed is $8.00/kg and the quantity of stock seed required for each target population was: 25, 30, 35, 40, 45 and 50 kg/ha respectively. Seeding rate required for each target population was determined using parameters of a nominal germination of 85%, 85% emergence of viable seeds planted and 14.5 g thousand seed weight (TSW).

In addition, at each site, yield and return per plot were each regressed against established plant population estimates for each plot, with the block effects also included in the statistical model. This enabled calculation of the slope of each trend line.

Results and Discussion

Populations

Plant populations established in the 2006-07 trial (124, 140, 176, 201, 224 and 260 plants/m^2) were very similar to the target populations (Table 1). Due to these results the same sowing calculation was used for the 2007-08 trial. However, plant populations recorded in 2007-08 were much higher than planned (185, 218, 259, 273, 287 and 346 plants/m^2 (Table 2)). These results suggest that there was close to 100% establishment of seed sown in 2007-08. The large difference between years can be partly explained by differences in trial sites. The 2007-08 Methven site was on an established arable farm in a field that was fully cultivated and had a pre-plant base fertiliser incorporated. Balanced site fertility, better seed-bed preparation and a more even watering system (overhead vs flood) no doubt improved seedling survival. In contrast, the Ashburton site used in 2006-07 was on a border-dyke irrigated, pastoral farm used for effluent disposal from a nearby meat and pelt processing facility. Long-term continual intensive forage removal with large machinery had resulted in soil compaction beneath the surface which limited soil aeration. Hemp prefers free-draining, well aerated soils (Bosca & Karus 1998). The field was also subject to effluent and pelt processing water which may have produced an unbalanced nutrient profile and subsequently affected plant establishment.

Yield

Machine dressed yields ranged from 804 kg/ha to 931 kg/ha in the 2006-07 trial (Table 1). When yield was plotted against established plant population, there was a positive linear trend ($P<0.05$). This was expressed by the equation: yield (kg/ha) = 719 + 0.823 x (plants/m^2), where the regression slope of 0.823 had a standard error of 0.339. The slope of 0.823 is interpreted as an extra 0.823 kg/ha of yield for every extra plant/m^2 established.

Yields achieved in year two were much higher, ranging from 1,640 to 1,849 kg/ha (Table 2). When yield was plotted against established plant population, there was a small but non-significant negative trend. This was expressed by the equation: yield (kg/ha) = 1751 – 0.069 x (plants/m^2), where the regression slope of –0.069 had a standard error of 0.513. The slope of –0.069 is interpreted as a loss of 0.069 kg/ha of yield for every extra plant/m^2 established.

The range in yield between years are similar to results from cultivar testing done previously in New Zealand, cited by McPartland *et al*. (2004), which reported average yields of 950-1,800 kg/ha depending on cultivar. To date, commercial yields for Fasamo in Canterbury have ranged between 400 and 1,000 kg/ha (unpublished data, Midlands Seed Ltd). Linear trend results suggest higher plant populations should be targeted when growing conditions are expected to be challenging. However, the greatest difference in yield was between sites and not between plant populations. This suggests that other aspects associated with the growing environment or crop management are more influential on oilseed yield than the established plant population. Fasamo demonstrated a high degree of flexibility with respect to yield and plant population, but showed a clear preference for a well prepared, free draining soil with ample water and nutrient availability.

Table 1 Established plant populations, seed yields and economic returns of cv. Fasamo over a range of plant densities in the 2006-2007 trial. Yields are machine dressed and corrected to 8% moisture content. Significance of linear trend was determined using the target plant populations.

Target Plant Population (plants/m^2)	Established Plant Population (plants/m^2)	Seed Yield (kg/ha)	Economic Return[1] ($/ha)
125	124	809	3482
150	140	804	3417
175	176	880	3725
200	201	887	3716
225	224	928	3863
250	260	931	3838
LSD (5%)	39	133	606
Signif. of lin. trend	0.1% sig.	5% sig.	not sig.

[1]Economic returns are before fixed production costs are accounted for.

Table 2 Established plant populations, seed yields and economic returns of cv. Fasamo over a range of plant densities in the 2007-2008 trial. Yields are machine dressed and corrected to 8% moisture content. Significance of linear trend was determined using the target plant populations.

Target Plant Population (plants/m^2)	Established Plant Population (plants/m^2)	Seed Yield (kg/ha)	Economic Return[1] ($/ha)
125	185	1671	7402
150	218	1823	8053
175	259	1640	7183
200	273	1849	8092
225	287	1724	7483
250	346	1696	7317
LSD (5%)	44	189	862
Signif. of lin. trend	0.1% sig.	not sig.	not sig.

[1]Economic returns are before fixed production costs are accounted for.

Table 3 Oil content and fatty acid composition of cv. Fasamo seed across plant populations tested in 2006-07. Fatty acids are expressed as a percent of total fatty acids.

Plant Population	Oil Content (g/100g)	Linoleic (%m/m)	α-linolenic (%m/m)[1]	Oleic (%m/m)	γ-linolenic (%m/m)	Palmitic (%m/m)	Steridonic (%m/m)
124	31.9	53.0	20.4	9.7	3.8	6.2	1.6
140	30.9	53.1	20.4	9.7	3.8	6.2	1.5
176	31.8	53.1	20.4	9.8	3.8	6.2	1.5
201	31.7	53.1	20.3	9.7	3.8	6.3	1.5
224	32.5	53.1	20.3	9.8	3.8	6.2	1.5
260	32.0	53.1	20.2	9.8	3.8	6.3	1.5

Note: Samples pooled across plots for each treatment so no statistical analysis possible.
[1]%mass/mass.

Economic Return

In 2006-07, the financial return to the grower ranged from $3,482/ha for 124 plants/m^2 up to $3,838/ha for 260 plants/m^2 (Table 1). When return was plotted against established plant population, there was a positive linear trend but this was not statistically significant (P=0.12). The relationship between economic return and established plant population was expressed by the equation: return ($/ha) = 3,216 + 2.44 x (plants/m^2), where the regression slope of 2.44 had an standard error of 1.49. The slope of 2.44 is interpreted as a net gain for the grower of $2.44/ha for every extra plant/m^2 established.

Higher yields in 2007-08 were reflected in greater financial returns (Table 2). In this season returns ranged from $7,317/ha to $8,092/ha, and again there was no significant relationship between established population and return. When return was plotted against established plant population, the outcome for the grower was in contrast to the year before, with a loss of $1.40/ha for every extra plant/m^2 established.

Oil Quality

Oil quality tests (Table 3) were run on pooled samples from the 2006-07 trial only, so no statistical analysis could be conducted. There were small differences in oil content across treatments, which ranged from 30.9-32.5 g/100g, but no consistent trend was evident. Plant population had a negligible effect on fatty acid composition (Table 3). In this trial, oil quality appears to remain stable across a range of populations.

General

From a practical point of view, low populations are not ideal for two reasons. Firstly hemp's ability to suppress weeds is reduced, leading to the need for herbicides to maintain high *C. sativa* seed purity. Limiting pesticide input is also appealing to the health food industry. Secondly, stands at low populations tend to produce tall plants with multiple, thick stems, which invariably lead to harvesting difficulties (Bocsa & Karus 1998 and Chen *et al*. 2004). Considering both practical and quantitative factors, it would appear that a target established plant population of 150-225 plants/m^2 is suitable for Fasamo oilseed production in Canterbury depending on site yield potential. This range is higher than the 90-120 plants/m^2 proposed by McPartland *et al.* (2004). However this work focused on maximum yield and not necessarily practical harvestability. Bocsa and Karus (1998) recommend 125-150 plants/m^2 for oilseed but mention that crops are not mechanically harvested. The actual amount of seed to plant is difficult to determine, as under favourable conditions emergence may get close to 100%, but may be reduce to less than 85% under more challenging conditions. Maximum yields and returns will be experienced when good general agronomic production practices are combined with favourable climatic conditions. Further work is required to define key agronomic management practices for this crop in Canterbury.

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References

Amaducci, S.; Pelatti, F.; Bonatti, P.M. 2005. Fibre development in hemp (*Cannabis sativa* L.) as affected by agrotechnique: preliminary results of a microscopic study. *Journal of Industrial Hemp 10*: 31-48.

AOAC. 2002. Official methods of analysis 17th Edition. Ed. Horwitz, W. AOAC International, Gaithersburg, Maryland, United States of America.

Bannon, C. D.; Craske, J. D.; Hilliker, A. E. 1985. Analysis of fatty acid methyl esters with high accuracy and reliability. IV. Fats with fatty acids containing four or more carbon atoms. *Journal of the American Oil Chemist Society 62*: 1501-1507.

Benhaim, P. 2003. A modern introduction to hemp from food to fibre past, present and future. 3rd Edition. Raw with Life, Mullumbimby, New South Wales, Australia. 51pp.

Bourrie, M. 2003. Hemp a short history of the most misunderstood plant and its uses and abuses. Firefly Books Ltd, Toronto, Canada. 160 pp.

Bosca, I. 1999. Genetic improvement: conventional approaches. pp. 153-184. *In*: Advances in hemp research. Ed. Ranalli, P. Food Products Press, New York, United States of America.

Bocsa, I.; Karus, M. 1998. The cultivation of hemp – botany, varieties, cultivation and harvesting. Hemptech, Sebastopol, California, United States of America. 184 pp.

Chen, Y.; Liu, J.; Gratton, J.L. 2004. Engineering perspectives of the hemp plant, harvesting and processing – a review. *Journal of Industrial Hemp 9*: 23-40.

Kear, B.S.; Gibbs, H.S.; Miller, R.B. 1967. Soils of the downs and plains, Canterbury and North Otago, New Zealand. NZ Soil Bureau Bulletin 14 R.E. Owen, Government Printer, Wellington, New Zealand. 92 pp.

Kelly, A.F.; George, R.A.T. 1998. Section II Seed growing of particular species – *Cannabidaceae*: agricultural crop. p. 163. *In*: Encyclopedia of seed production of world crops. John Wiley & Sons, Chichester, West Sussex, United Kingdom.

McIntosh, D.J.; Barge, R.; Brown, T. 1998. The 5 minute guide to industrial hemp in New Zealand. NZ Hemp Industries Association Inc, Auckland, New Zealand. 63 pp.

McPartland, J.M.; Cutler, S.; McIntosh, D.J. 2004. Hemp production in Aotearoa. *Journal of Industrial Hemp 9*: 105-115.

Ministry of Health. 2008. Sale of hemp seed oil as food. Retrieved 20 October, 2008 from http://www.moh.govt.nz/moh.nsf/indexmh/medicinescontrol-industrialhemp

New Zealand Food Safety Authority. 2008. Medicines control industrial hemp. Retrieved 20 October, 2008 from http://www.nzfsa.govt.nz/consumers/chemicals-nutrients-additives-and-toxins/hemp-seed-oil-as-food

Plant Research (NZ) Ltd. 2002. Growers guide for Fasamo industrial hemp seed production. Plant Research (NZ) Ltd, Lincoln, New Zealand. 12 pp.

Ranalli, P. 1999. Agronomical and physiological advances in hemp crops. pp. 61-84. *In*: Advances in hemp research. Ed. Ranalli, P. Food Products Press, New York, United States of America.

Roulac, J.W. 1997. Hemp horizons: the comeback of the world's most promising plant. Chelsea Green Publishing Company, Vermont, United States of America. 211 pp.

Saville, D.J. 1983. Statistical analysis of the economics of experimental treatments. *New Zealand Journal of Experimental Agriculture 11*: 1-3.

West, D.P. 1998. Hemp and Marijuana: myths & realities. Report produced for the North American Industrial Hemp Council. 28 pp. Retrieved 20 October 2008 from http://www.naihc.org