Plant density effects on yield parameters of three industrial hemp cultivars in the Manawatu

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Abstract

Industrial hemp (*Cannabis sativa* L) is a fast-growing annual multi-purpose crop grown for its fibres, hurd/shivs (woody inner core), seeds and pharmaceuticals. The commercial production of hemp is strictly legislated and only approved cultivars with delta-9-tetrahydrocannibinol (THC) levels under 0.35% are permitted in New Zealand. The effect of sowing rates and row spacing were studied for three industrial hemp cultivars (Kompolti, Fasamo, Ferimon 12) in the Manawatu region. Four sowing rates at two row spacings achieved a range of plant densities (25-110 plants/m^2). Plant heights were ca 2 m under most combinations except at lower sowing rates at the 10 cm row spacing where height was significantly higher. For all three cultivars, the higher plant populations (at 40 kg/ha) at 20 cm spaced rows (achieving over 100 plants/m^2) were doubling both dry stem yield and total fresh biomass at final harvest compared to the higher plant populations (at 40 kg/ha) at 10 cm spaced rows (achieving over 80 plants/m^2). Seed yields were not monitored. Despite the short season the total fresh biomass yield peaked at ca 30 t/ha for both Kompolti and Ferimon 12, and ca 25 t/ha for Fasamo but the peak yield was obtained at lower sowing density for 10 cm row spacing compared to the higher sowing density for 20 cm row spacing. A similar trend was observed for the stem dry weight for higher sowing rates at 20 cm row spacing achieving ca 5.5-6.5 t/ha dry stem yield for Kompolti and Ferimon 12, while 4 t/ha dry stem yield was observed for Fasamo. However, at 10 cm row spacing the stem dry weight was negatively affected by increasing sowing rates.

Additional keywords: *Cannabis sativa* L., plant population, sowing rates, row spacing, stem dry yield, total fresh biomass, fibre, fiber, Kompolti, Fasamo, Ferimon 12.

Introduction

Industrial hemp (*Cannabis sativa* L.) is a tall-growing short-season species grown world-wide for its bast fibre and hurd (woody inner core), seed (including oil) or as a dual-purpose crop gaining significant renewed global interest and creating renewed opportunities as an ancient crop (Fike, 2016). Hemp is a herbaceous annual with a deep tap-root and woody stem(s) that can grow to a height of 4 m depending on variety and growing conditions. Hemp plants are originally dioecious (separate male and female plants), but monoecious varieties with male and female parts on the same plant also exist (Bouloc *et al.*, 2012). Industrial hemp is a promising and potentially valuable cash-crop worth exploring its full potential for New Zealand. Growing hemp is not difficult: the crop requires little or no biocide, suppresses weeds efficiently and has limited demands with respect to fertiliser usage or crop rotation (Van der Werf *et al*., 1994), but is sensitive to poor soil structure and shortage or excess of water during early stages of growth, and thus needs well-drained soil types (Struik *et al*., 2000). It grows in a range of climates, but is best suited to temperatures between 15 and 27 °C and generally requires 1,900-2,000°C growing degree days (GDD) to reach fibre maturity and 2,700-3,000°C GDD for seed production (Cole and Zurbo, 2008; Bouloc *et al.,* 2012). Hemp is a short-day plant and when grown for fibre production averages to be a 100-120 day crop in New Zealand where it is generally sown before mid-October and harvested between February and April (Merfield, 1999; McPartland *et al.,* 2004), and typically ca 500 GDD per month on average are accumulated over the summer (Nov-Mar) in Palmerston North (Merfield, 1999). Hemp is frost sensitive, but has the ability to grow at low temperatures >1°C (Lisson and Mendham, 2000). Hemp is high yielding, versatile, grows in a range of agro-ecological conditions, and is attractive for use in low-carbon manufacturing and is of interest as a renewable industrial material. Cannabis contains the narcotic compound delta-9-tetrahydrocannibinol (THC), marijuana cannabis has higher levels of THC compared to low THC industrial hemp cannabis. The Ministry of Health in New Zealand have approved 12 industrial hemp cultivars that produce THC levels of <0.35% which are permitted to be grown under licence (MoH, 2017). Global interest in the potential of industrial hemp has continued to increase through research and investigations into uses, sustainability and opportunities for hemp (Amaducci *et al.,* 2015). The cultivated area in Europe increased continuously in the years 2012 to 2016 with more than 33,000 ha reported in 2016 with main areas in France, the Netherlands, the Baltic Countries and in Romania (EIHA, 2017).

The commercial production of industrial hemp in New Zealand so far has mainly focused on hemp seed oil production from crops grown in the Canterbury region (Townshend and Boleyn, 2008). Just recently (April 2017) the Food Standards Australian New Zealand (FSANZ) announced the approval to permit the sale of low-THC hemp seed food for human consumption in New Zealand and Australia (FSANZ, 2017), which will further boost the area of industrial hemp cultivation in New Zealand and Australia, along with the so far small-scale cultivation of hemp for fibre for paper, clothing and building products.

Plant density is as an important tool to obtain fibre quality. Struik *et al.* (2000) and Van der Werf (1995) reported significant self-thinning at higher plant densities creating heterogeneity.

Therefore the aim of this study was to determine the plant population effects for stem yield related to fibre production for three industrial hemp cultivars (Fasamo, Ferimon 12 and Kompolti) within two different row spacings in the Manawatu region.

Materials and Methods

The trial was conducted at the Plant Growth Unit (40° 38’ S, 175° 61’ E) at Massey University, Manawatu during the 2016/2017 season. The soil type for the trial is a Turitea silt loam, with good drainage and sufficient plant available water capacity.

A randomised, split plot trial plan was designed, composing trial land area of 96 m x 32 m, split into 96 plots of 8 m x 4 m. Four replicates (n=4) were established of three cultivars, four sowing densities and two row spacings. Each replicate contained 24 plots, with 12 plots sown with 20 cm row spacing and 12 plots were sown with 10 cm row spacing. Following a very wet spring (Sept-Nov 2016, ca 309 mm, which was classified as ‘well above normal rainfall’; NIWA, 2017), the trial area was finally prepared in early December: being ploughed, cultivated into fine tilth, levelled, and rolled. The seed was sown on the 21 December 2016, using a direct-drill (cone) seeder, with a sowing depth of approximately 1.0 - 1.5 cm.

The hemp (*Cannabis sativa* L) cultivars used were; ‘Fasamo’ (monoecious, German bred, dual purpose), ‘Ferimon 12’ (monoecious, French dual purpose) and Kompolti (Hungarian dioecious). Sowing densities were 5 kg/ha, 10 kg/ha, 20 kg/ha and 40 kg/ha. Pre-sowing germination testing performed for all three cultivars was high (> 90%) and rates were adjusted accordingly. The trial area came out of long-term perennial ryegrass and no additional fertiliser was applied. No weed, pest and disease control was conducted throughout the trial.

Emergence counts were conducted from 1 m^2 areas within each plot, and were recorded several times until counts were considered constant. Plant growth stages were noted throughout the trial (such as flower emergence), and plant height measurements taken frequently from January to March – measured by taking the average height from five plants in the middle square metre of each plot.

Final sample harvest occurred 15 March 2017, when majority of plants had reached peak fibre maturity prior to seed set. A 1 m^2 area was measured in the centre of each plot, and all plants in this area removed. Height and fresh weight measurements were taken, and then a subsample (3 representative plants) was taken. The subsamples were fresh weighed before and after the leaves and flowers had been removed. Sub sample stems were dried in an oven at 75°C for 5 days, before the dry weight of each sub sample was taken. The levels of THC were tested for a combined sample for each cultivar at harvest by the Auckland Drugs Laboratory at the Institute of Environmental Science and Research Limited (ESR) as part of the MoH licencing requirements stating that THC levels at any time should be < 0.35%.

Statistical analysis was carried out using Minitab.

Results and Discussion

The focus of this experiment was to assess the stem yield (for fibre/hurd applications) and seed production was not assessed. Hemp fibre crops are generally harvested well before development of the seed heads and seed set when stem and fibre yield has reached its maximum which maintains a better decorticated fibre/hurd quality as well (Cole and Zurbo, 2008). The late sowing date in December was a consequence of a very wet spring which resulted in a short-season crop. No late frosts were recorded. The plant height for the three cultivars were followed throughout the season, the average plant height at final harvest in March was ca 2 m. Kompolti at low sowing rates showed a significant increase in height for the 10 cm row spacing, as did Fasamo. At higher sowing rates there was a slight tendency to grow taller for the 20 cm row spacing (data not shown). Campiglia *et al.* (2017) observed similar plant heights (2-2.5 m) for seven European cultivars, including Ferimon 12, with slightly shorter heights at higher plant densities. For hemp seed yield, Townshend and Boleyn (2008) found no significant plant density effects on hemp seed yield and economic return using a dual-purpose cultivar Fasamo in Canterbury and recommended a plant population of 150-225 plants/m^2 for seed oil production in Canterbury. Several European studies recorded relative small effects of plant density on hemp seed yield (Dan *et al*., 2015; Stafecka *et al*., 2016). Lower seeding densities for seed crops generally allows for greater branching and shorter plant height compared to fibre crops at higher densities, suppressing branching and inducing taller and lighter individual plants in the latter (Hall *et al.*, 2014). For fibre production wide-ranging populations (30-500 plants/m^2) have been reported (Dempsey, 1975; Cole and Zurbo, 2008; Amaducci *et al.*, 2015), but a detailed study Struik *et al.* (2000) stated the effects of plant density (ranging from 30-270 plants/m^2) on above-ground and stem dry matter in fibre hemp were small and not significant, but highlighted that initial plant density (ca. 30-90 plants/m^2) as an important tool to obtain fibre quality, while higher plant densities (over 180 plants/m^2) showed significant self-thinning creating heterogeneity (Van der Werf *et al*., 1995; Struik *et al*., 2000). The seed rates of 5–40 kg/ha for all three cultivars achieved a range of 25-87 plants/m^2 and 30-110 plants/m^2 for 10 cm and 20 cm row spacing respectively (Table 1).

Table 1: Established plant populations ± SE (plants/m^2) for hemp cultivars Kompolti, Fasamo and Ferimon 12 for four sowing rates (5, 10, 20, 40 kg/ha) at 10 and 20 cm row spacings.

Cultivar	Seed rate (kg/ha)	Row spacing 10 cm (plants/m^2)	Row spacing 20 cm (plants/m^2)
Kompolti	5	47.8 ± 6.3	31.3 ± 6.2
	10	79.5 ± 8.0	44.3 ± 5.6
	20	89.3 ± 15.0	60.5 ± 4.3
	40	95.3 ± 12.5	97.8 ± 9.1
Fasamo	5	24.8 ± 2.1	34.0 ± 3.9
	10	59.3 ± 6.4	47.5 ± 7.8
	20	56.0 ± 3.7	55.3 ± 7.5
	40	82.0 ± 15.1	109.3 ± 8.4
Ferimon 12	5	44.8 ± 4.5	29.5 ± 5.4
	10	61.5 ± 8.3	40.3 ± 5.6
	20	55.8 ± 2.8	66.8 ± 5.8
	40	87.3 ± 14.5	104.3 ± 10.5

Figure 1 shows the plant density for the 10 cm row spacing showing a slight upward trend for stem dry weight and total fresh biomass for both Kompolti and Fasamo but a negative effect on stem dry weight and total fresh biomass is seen for Ferimon 12, while stem dry yield is relative constant for all sowing densities at 10 cm row spacing (Figure 1). At 20 cm row spacing both Kompolti and Ferimon 12 are showing a strong positive effect of sowing rates on both stem dry yield and total fresh biomass (Figure 1); this effect is less pronounced for Fasamo. Figure 1 shows for all three cultivars that higher plant populations at 20 cm spaced rows (achieving over 100 plants/m^2) were significant higher for both dry stem yield and total fresh biomass at final harvest compared than the higher plant populations at10 cm spaced rows (achieving over 80 plants/m^2), which is fascinating giving possibly driven by subtle changes in competition for light and other inputs. Given the dual-purpose nature of the cultivars used, to use different row spacings might be a possible tool to maximise both stem and seed yields. Further research using exact hand-thinned plant populations with different row spacings will be needed to quantify this in its specific yield components (Hall *et al.*, 2014). The level of THC in each of the varieties used were below 0.1% (tested by the ESR-Auckland Drugs Laboratory; data not shown).

A large degree of heterogeneity was observed in the dioecious cultivar Kompolti as a consequence of rate of growth and development between male and female plants, with the male plants tending to flower and senesce earlier, which makes this cultivar not ideal for fibre purposes. Even in monoecious varieties larger plants might suppress the smaller ones (i.e. self-thinning) as described by Van der Werf *et al.* (1995) but there was only some evidence (data not shown) of self-thinning effects at higher sowing rates in our trial. For seed production, densities in the range of 30-70 plants/m^2 equating to 5-25 kg/ha (McPartland *et al.*, 2004; Cole and Zurbo, 2008) are used. Townshend and Boleyn (2008) reported a target population of 150-225 plants/m^2 for Fasamo oilseed production under Canterbury conditions.

Dry stem yields from cultivars for dual-purpose production in Europe under contrasting environments were reported to be between 4-22 t/ha (Lisson and Mendham, 2000, Tang *et al*., 2016), and 10-12 t/ha in NSW under irrigation (Cole and Zurbo, 2008). Reported dry stem yields (Figure 1) ranging from 1.4-4.8 t/ha (10 cm row spacing) and from 1.6-6.5 t/ha (20 cm row spacing) are a little higher to these reported by Hall *et al*. (2014) under Queensland conditions. Given the short-day nature of the crop affecting onset of flowering (Struik *et al*., 2000; Cosentino *et al*., 2012; Hall *et al*., 2014) it is crucial for New Zealand to have access and/or select for later cultivars bred for higher latitudes which will increase the yield potential (given sowing will be earlier than our late Dec 2016 sowing).

Commercial industrial hemp is a multi-purpose crop given its fibre, hurd (core) and seed (food/oil), produced from the current approved most dual-purpose cultivars. Carus *et al.,* (2013) referred to these products with the highest future growth potential in Europe. As the only remaining countries in the world, New Zealand and Australia repealed in April 2017 the ban to use hemp seed for human consumption, alongside hempseed oil which was allowed in New Zealand and Australia (FSANZ, 2017). This will create a focus on hemp foods in New Zealand along with other

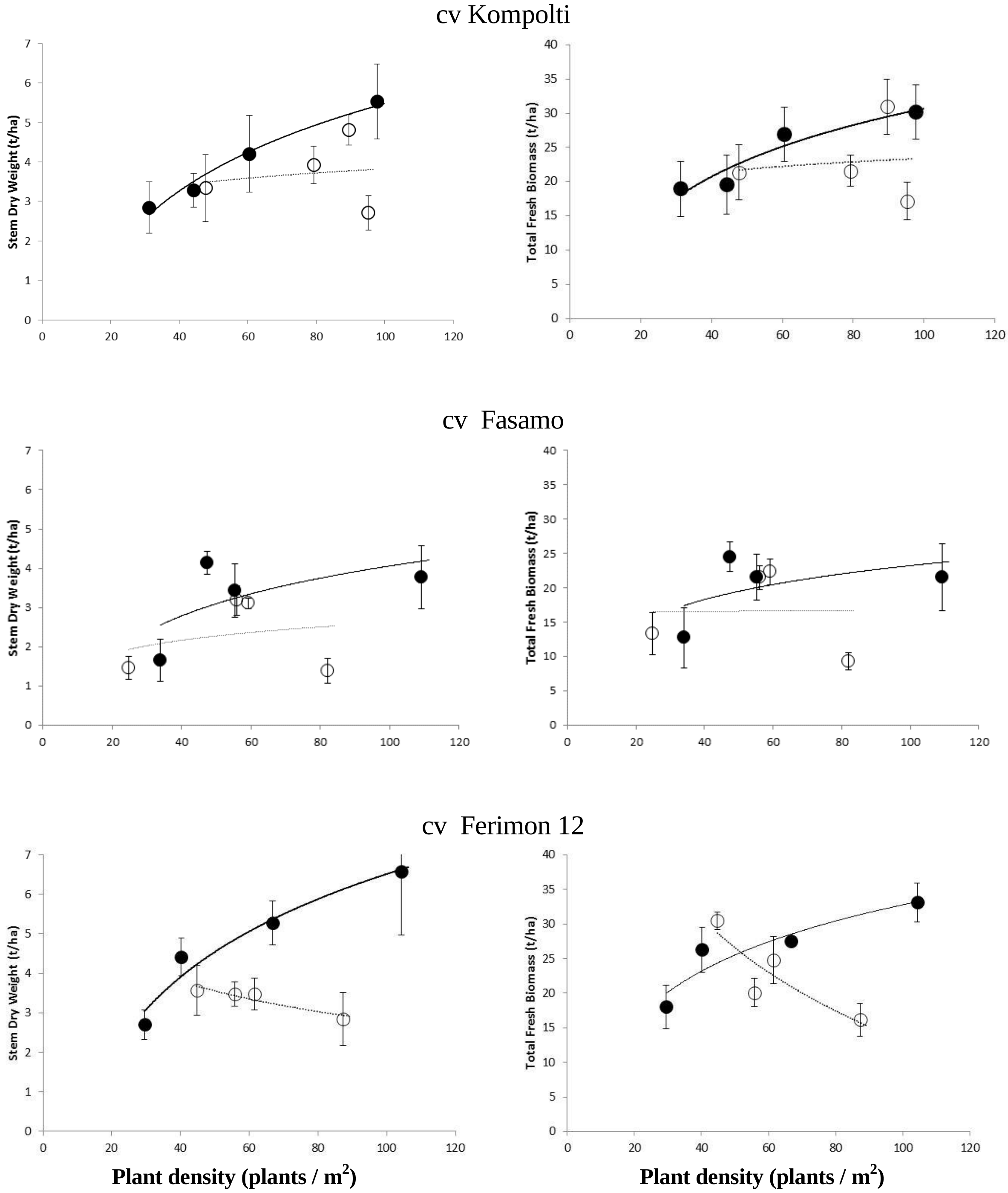

Figure 1: Stem dry weight ± SE (t/ha) [left] and total fresh biomass ± SE (t/ha) [right] for hemp cultivars Kompolti, Fasamo, and Ferimon 12 for realised plant densities following four sowing rates (5, 10, 20, 40 kg/ha, see Table 1) for 10 cm row spacing (open symbols) and 20 cm row spacing (closed symbols). SE is standard error (n=4).

uses. Hemp is a relatively new crop to New Zealand and as of January 2015 twelve industrial hemp cultivars (dual-purpose; dioecious/monoecious) are approved for NZ (MoH, 2017). Predicted returns are conservatively estimated between $5-7k per hectare with establishment costs similar to maize, but better harvesting and decorticating methods (to separate the fibre and hurd from the stems) need to be developed (Dave Jordan, NZ hemp pioneer – pers. comm., 2017). The potential for NZ is currently explored with several industrial hemp initiatives in various regions with ca 40 commercial, mostly small-scale, hemp farmers along with some several iwi initiatives in NZ aiming to build a combined area well over 100 ha which will build capacity and create jobs and opportunities in regional New Zealand. Further trials will be required to evaluate dual-purpose performance of the current approved and new-incoming hemp varieties under New Zealand regional conditions.

Conclusions

All three hemp cultivars studied for fibre showed that higher plant populations at seed rate of 40 kg/ha at 20 cm spaced rows (achieving over 100 plants/m^2) were doubling both dry stem yield and total fresh biomass at final harvest compared than the higher plant populations at similar seed rate of 40 kg/ha at 10 cm spaced rows (achieving over 80 plants/m^2). Typical peak dry stem yields were 5.5, 3.7 and 6.6 t/ha for Kompolti, Fasamo and Ferimon 12 respectively at 20 cm row spacing. Further trials are needed to further evaluate dual-purpose performance given the FSANZ announcement that hempseed foods will be legalised for human consumption in 2018.

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