Effect of industrial hemp (*Cannabis sativa* L) planting density on weed suppression, crop growth, physiological responses, and fibre yield in the subtropics

Jack Hall, Surya P. Bhattarai* and David J. Midmore

*Correspondence: s.bhattarai@cqu.edu.au

Central Queensland University, Rockhampton, QLD 4702 Australia.

### Abstract

Population density of industrial hemp (*Cannabis sativa* L.) in the field influences crop growth habit, fibre yield and quality. Therefore, optimization of plant population density is required to control growth and secure fibre yield and quality. Initial hand-thinned plant populations of 100, 200, 300 and 400 plants m$^{-2}$ were established in a replicated field trial. Density of planting significantly influenced weed suppression and a number of phenological characters, and yield of industrial hemp. Weed suppression increased with increasing plant population. An increase from 100 to 200 plants m$^{-2}$ markedly reduced weed weight from 23.2 to 6.5 g m$^{-2}$. Further reductions in weed weights were observed at 300 plants m$^{-2}$ (2.6 g m$^{-2}$) and 400 plants m$^{-2}$ (1.5 g m$^{-2}$). Weekly height data showed that the high-density plantings resulted in shorter plants at harvest due to a more rapid decline in growth rate than for the low density planting (100 plants m$^{-2}$). Stem thickness was inversely related to plant population density as low density produced thicker stems compared to that of high density planting. Leaf chlorophyll content and root mass m$^{-2}$ were not significantly affected by differences in planting density. Raw fibre yields were greatest at 300 plants m$^{-2}$, which was significantly higher in comparison to 100 plants m$^{-2}$ (128.4 vs 102.8 g dry weight m$^{-2}$). Yields were very poor overall with a maximum of 1.28 t ha$^{-1}$ of raw bast when compared to European yields of 2–3 t ha$^{-1}$. Low yields were attributed to the unsuitable short photoperiods that caused early flowering and therefore shorter stem length in the current variety under trial. New varieties or crop management practices that delay flowering are necessary for regions of short day duration to produce economically viable fibre yields for the industry in subtropical Queensland, Australia.

**Keywords:** Industrial hemp, planting density, fibre yield, new crop

### Introduction

Economic efficiency of planting a crop such as industrial hemp (*Cannabis sativa* L.) from seed requires the establishment of ideal sowing rates (kg seed ha$^{-1}$) which determine the final plant population (plants m$^{-2}$). Under-sowing may result in undesirable product qualities and poor yield [17] in addition to increased competition by weeds [16], harvesting difficulty associated with thicker stems [6] and particularly reduced radiation use efficiencies [8]. Excessive planting densities in hemp crops result in increased self-thinning and a slowing down of crop growth rate in later stages of development [19]. The appropriate density of planting varies with variety, season, soil type and range of other agronomic practices adopted for the crop. Hence, seeding density for any variety should be optimised for the particular location of interest.

Industrial hemp is also sown at differing density depending on the purpose of the crop: whether it is for fibre or grain. Recommended seed rate for the latter (a seed crop) is often around 30 kg ha$^{-1}$ or between 100–150 plants m$^{-2}$ [6]. Low seeding density for a seed crop allows for greater branching, shorter plant height and heavy individual plant weight compared to fibre crops sown at higher density. The latter suppresses branching, induces taller and lighter individual plants. Harvesting of hemp crops for fibre at maturity is much easier when plants are upright and have few branches, and the quality of fibre is better in unbranched plants.

Planting density for fibre hemp is roughly twice that of seed hemp. Early research [6] suggest that no more than 80 kg seed ha$^{-1}$ be sown for fibre hemp as little differences in final yields were observed between 60–100 kg ha$^{-1}$ (300–500 plants m$^{-2}$). These rates are considered, however, excessive for non-textile fibre hemp that is produced for volume of fibre rather than quality. Sowing rates for non-textile fibre may be adequate at 30 kg ha$^{-1}$ [9]. High sowing rates generally produce shorter, thinner stemmed plants [2] with a higher proportion of fibre in the stem material which is desirable for fibre hemp [19].

Seeding rate, depending on intended use, may not change greatly between varieties. In a study conducted in Wales by [5] five varieties were sown at 150 and 300 plants m$^{-2}$. Results indicated that although final total fibre yield increased at the higher density, no inter-varietal interaction with seeding rate was observed. The proportion of fibre in the harvested straw increased slightly at the higher density despite the proportion of long fibre remaining the same. Hemp fibre yields of around...
2–3 t ha⁻¹ and final plant heights of 1.5–3.0 m are typical of economically viable hemp crops in Europe [6].

Crop maturity, with respect to harvest times, is often not well defined in the literature and differs depending on final crop use or the opinion of the researcher [11]. Harvest times for the current experiment were based on growth rates (harvest was conducted when plant heights ceased to increase), which may have affected the quality of the final bast fibres.

This study examines the effects of varying level of population densities, from those considered low to high density plantings, on control/suppression of weed, crop growth parameters, yield and quality of a subtropical hemp variety (BundyGem) in a sub-tropical location of Queensland, Australia with the aim of developing recommendations for optimum sowing rates for production of hemp fibre and seed crop by this variety in a ferrosol.

**Materials and methods**

**Location**

A field trial was conducted in the spring-summer season of 2010 consisting of two sowing times (October 1 and October 15) in Bundaberg, QLD (24.91˚S 152.32˚E Alt 17.1 m). The site chosen was a quarter hectare block on a red clay loam (ferrosol) typical of volcanic soil found in the region. The proximate analysis of the soil and irrigation water for nutrient and ions are summarized in Tables 1 and 2 respectively. The data in Tables 1 and 2 indicate that the soil and water nutrient contents were within the range but insufficient to provide adequate nutrient to the plant, hence supplementary fertilizer was applied to the crops (Table 3) to meet the crop nutrient requirements.

**Description of trial**

The trial was a complete randomised block design consisting of four planting densities and four blocks within each time of planting. Data for the two planting times were retrospectively combined when analysis showed no planting time interactions with density. Initial (post thinning) plant

| Parameter | Nutrients and soil characteristics | Concentration |
|-----------|----------------------------------|---------------|
| Ammonium N (mg kg⁻¹) | 4 |
| Nitrate N (mg kg⁻¹) | 20 |
| P (mg kg⁻¹) | 114 |
| K (mg kg⁻¹) | 189 |
| S (mg kg⁻¹) | 13.7 |
| Organic matter (%) | 1.28 |
| EC (dS/m) | 0.091 |
| pH (CaCl₂) | 6.5 |
| pH (H₂O) | 7.3 |

Table 1. Soil analysis of the red soil (ferrosol) in the planting density trial.

| Elements          | Concentration       |
|-------------------|---------------------|
| Ammonium N        | <0.10 mg L⁻¹        |
| Nitrate N         | 10.93 mg L⁻¹        |
| B                 | 0.08 mg L⁻¹         |
| Ca                | 38.49 mg L⁻¹        |
| Cl                | 743.52 mg L⁻¹       |
| Cu                | <0.05 mg L⁻¹        |
| Fe                | <0.05 mg L⁻¹        |
| Mg                | 126.8 mg L⁻¹        |
| Mn                | 0.06 mg L⁻¹         |
| P                 | <0.05 mg L⁻¹        |
| K                 | 1.51 mg L⁻¹         |
| Na                | 193.6 mg L⁻¹        |
| S                 | 16.83 mg L⁻¹        |
| Zn                | <0.05 mg L⁻¹        |
| EC                | 2.029 dS/m          |
| pH                | 6.4                 |

Table 2. Analysis of irrigation water used for plant density trial.

| Location GPS location | Bundaberg 24.91˚S 152.32˚E, Alt 17.1 m |
|-----------------------|---------------------------------------|
| Planting times        | 1 Oct 2010 and 15 Oct 2010             |
| Plant densities after thinning | 100, 200, 300 and 400 plants m⁻² |
| Row spacing           | 10 cm                                 |
| Plot size             | 3 m x 3 m                             |
| Harvested area within plots | 1 m²                                  |
| Soil type             | Red clay-loam (ferrosol)              |
| Applied elemental nutrients (kg ha⁻¹) | --                                    |
| N                     | 120                                   |
| P                     | 15                                    |
| K                     | 32                                    |
| Precipitation¹ and irrigation (mm): Oct 1 to Dec 18 | 620 |

¹Source: (BOM, 2012) For precipitation data

Table 3. Details of plant density trial.

The industrial hemp variety selected for the trial was an improved subtropical variety, BundyGem, with low delta-9-tetrahydrocannabinol (THC) content, descended from Canadian stock. The use of a single variety in the experiment
Figure 1. Planting date 1 (1st Oct) showing the difference in plant populations between the plots.

Figure 2. Plant densities 1 (D1) (left and 4 (D4) (right) after hand thinning.

reflects the lack of current varieties suitable for cultivation at the selected (short-day) latitude. It also assumed that no interactions exist between fibre variety and sowing density, an assumption supported by earlier research conducted by [5]. The same variety was also used in other experiments (time of planting, and photoperiod trials) as reported in [11-13].

Planting and crop maintenance
The details of planting date, densities, plot size, spacing, sample plot for harvest, NPK inputs and total crop water inputs during the growing season are presented in Table 3. Seeds were planted in shallow furrows spaced 10 cm apart and after emergence hand thinned (within 1 week of full emergence) to the desired populations before an obvious between-plant competition could be observed visually.

Each planting received a basal application of superphosphate (168 kg ha⁻¹ containing 9% P) on the date of sowing followed two weeks later by an application of urea at 135 kg ha⁻¹. This was to ensure early development was unimpeded by poor nutrition. Subsequent applications of soluble N32 (32% N) and potassium nitrate (KNO₃) were delivered in solution through the drip irrigation. Total applied nitrogen, based on relatively low soil N, was 120 kg ha⁻¹ which is the upper limit for fibre hemp suggested by [4]. A maintenance application rate of phosphate (15 kg ha⁻¹) reflected high soil available phosphorus. Potassium application rates (32 kg ha⁻¹) may have been somewhat low considering the concentration of magnesium in the irrigation water, which may have affected the cation balance.

Irrigation was supplied using drip tape spaced at 20 cm intervals and placed on every second inter-row to maximise irrigation uniformity. Soil moisture was determined using John Deere CropSense soil moisture probes (data not shown) and used to determine appropriate watering times. A total of 550 mm was supplied to the crop through irrigation. Precipitation was 255 mm for the area over the course of the trial, of which, a large proportion was skewed toward the harvesting period of the crop (Figure 3) interfering with crop senescence. Ambient temperature during the crop growing period was moderate and gradually increased towards crop maturity. The minimum temperature during the crop period ranged from 15–20°C whereas the maximum temperature during the crop period ranged from 22–33°C (Figure 4). The trial site received daily

Figure 3. Daily rainfall for Bundaberg (Sept 15–December 31, 2010) Source: (BOM, 2012).

Figure 4. Average daily maximum and minimum temperatures for Bundaberg, October to December 2010 Source: (BOM, 2012).
average solar radiation over the range 10–30 MJ/m² (Figure 5).

**Weed growth and biomass**

All weeds (aboveground only) were collected from each harvested 1 m² plot at the same time as the hemp plants, and the dry weights recorded. Weed species that were common to the harvested areas were recorded and total dry weights from each harvested plot were analysed for the purpose of determining the effects of planting density on weed suppression.

**Plant growth and physiological response**

Plant height measurements were taken at weekly intervals during vegetative growth until harvest with roughly three females and three males selected in each plot for measurement. Heights were measured from the base of the plant to the growing tip and rounded to the nearest 5 mm.

Chlorophyll concentration was estimated on two occasions during vegetative growth with a Konica Minolta SPAD-502Plus chlorophyll meter. At harvest, plant heights and stem diameters at 100 mm above ground level (using Kinchrome digital vernier callipers) were measured on 10 plants from each plot.

**Hemp harvest and yield**

Final harvest was conducted when increase in overall crop height had ceased and plants were fully flowering. Harvest dates were the 3rd December (1st planting) and 18th December (2nd planting). Sections of 1 m² from each plot were harvested by hand removing entire plants, including sturdy but not fibrous roots. Harvested plants were allowed to air dry in a holding shed for 1 month before being decorticated in a series of mechanical rollers to remove hurd. The process consisted of eight passes through the mechanical decorticator per sample. After eight passes fibre samples were free of most of the hurd and other non-fibrous plant materials. The remaining raw bast fibre was dried and weighed for final analysis. Root and stem fibre and hurd, and weed samples, were placed in paper bags or aluminium trays in drying ovens for 24 hours at 75°C. The raw fibre weight was used to give a relative indication of yield but not intended to determine quality of the final product which was beyond the scope of the experiment.

**Pest and disease control**

Some spraying was conducted at the periphery of the plot borders to control grasses using Fusilade Forte 128 EC (Syngenta). Some insect pests were also sprayed during the trial including green vegetable bug (*Nezara viridula*), red-shouldered leaf beetle (*Monolepta australis*) and budworm (*Helicoverpa*) using endosulfan.

**Statistical analysis**

Data were analysed using GENSTAT 13 statistical program using ANOVA at the 0.05 level of significance.

**Results and discussion**

**Soil and water**

Table 1 indicates that the soil had sufficient nutrient, e.g., nitrate nitrogen, an appropriate pH and other conditions suitable for hemp growth. Similarly the analysis of irrigation water (Table 2) showed that the irrigation water quality parameters were satisfactory, with respect to pH, EC and nitrate content in the water sample. Both soil and water analyses suggest that the soil and water conditions were favourable for hemp growth. The crop was grown under optimum crop nutrition (Table 3), hence the crop was not nutrient limited for growth in the field.

**Weed growth dynamics**

Diverse weed species (nine species) appeared in the trials plots. Fat hen (*Chenopodium album*), and Couch grass (*Cynodon dactylon*) were the dominant species (Table 4).

| Common name       | Botanical name          | Proportion of weeds present (%) |
|-------------------|-------------------------|---------------------------------|
| Fat hen           | *Chenopodium album*     | 20–30                           |
| Couch grass       | *Cynodon dactylon*      | 15–20                           |
| Liverseed grass   | *Urochlea panicoides*   | 10–15                           |
| Mossman river grass | *Cenchrus echinatus*  | 5–10                            |
| Milkweed          | *Euphorbia heterophylla*| 5–10                            |
| Passalum          | *Passalum dilatatum*    | 5–10                            |
| Cobbler pegs      | *Bidens pilosa*         | 1–2                             |
| Spiny emex        | *Emex australis*        | 1–2                             |
| Common thistle    | *Sonchus oleraceus*     | >1                              |

Weed dry weights for the lowest planting density D1 (100 plants m⁻²) were significantly greater than weed dry weights of all other planting densities (Table 5). Weed dry weights decreased significantly (weed suppression by increased...
density of seeding) from 23.2 g m$^{-2}$ at 100 plants m$^{-2}$ to 6.5 g m$^{-2}$ when density increased to 200 plants m$^{-2}$ (D2). A further decrease in weed weight with increased density to 300 and 400 plants m$^{-2}$ (D3 and D4) was observed, however, the rate of reduction was not significant as the density increased above 200 plants m$^{-2}$.

The marked decrease in weed pressure as the population of hemp increased is undoubtedly a function of increased inter-species competition for light and other resources. A sharp reduction in weed dry weights from 100 to 200 plants m$^{-2}$ indicates that a population threshold above 200 plants m$^{-2}$.

Weeds are a major problem for establishment of hemp in the field. Various weed species, specific to the local production area exert severe competition with the crop for soil nutrient, water, space, light, and complicate harvest and impair quality of the produce. The results of this trial suggest that control of weed is possible by adjusting an appropriate seeding density for the crop.

### Stem thickness

Stem thickness showed a clear inverse relationship with sowing density (Table 6) as previous research suggests [2,14] but the relationship was stronger between D1 and D2 than between D2, D3 and D4. D1 had on average much thicker stems than the other treatments. Male plants were noticeably thinner than females at all planting densities. Stems of D4 tended to be thinner than those of the other treatments.

The notable decrease in stem diameter between 100 and 200 plants m$^{-2}$ indicates that a population threshold was exceeded, whereby robust, thick individual plants that were common at the lower population and low competition densities diminished with increasing population. Increasing plant density results in thinner stemmed plants, which are preferable for fibre production [19]. Although the increase of planting density increased the weed suppression, and decreased stem thickness, there was no significant effect observed on the leaf chlorophyll content (Table 6).

### Plant height

During early vegetative growth, 25 days after planting, plant height was greatest at D3. Plants in this treatment were significantly taller than those in D1 and D4 (Table 7). Plants in D4 were also considerably shorter than those in both D2 and D3. One week later measurements of the same plants showed no significant differences in height between treatments. At day 39, there were indications that growth rates for D3 and D4 were slowing more than those of the lower densities. By day 46, D1 was much taller on average than both D3 and D4. The original growth trend, favouring 300 plants m$^{-2}$ (D3), had changed to favour the lowest plant density at the time of the final data collection. The plant density with the greatest mean plant height at day 53 was D1: significantly taller (but only by about 10%) than both D3 and D4. Across all plant

### Table 5. Mean weed, root, stem and bast, total stem yields and percentage raw bast in stems.

| Plant population (* m$^{-2}$) | Weed DW (g m$^{-2}$) | Root DW (g m$^{-2}$) | Total stem field DW (g m$^{-2}$) | Raw bast in stem (%) | Raw bast DW (g m$^{-2}$) |
|-------------------------------|---------------------|---------------------|---------------------------------|---------------------|---------------------|
| D1 (100) | 23.2 | 44.8 | 384 | 29.56 | 102.8 |
| D2 (200) | 6.5 | 45.3 | 419 | 30.03 | 114.5 |
| D3 (300) | 2.6 | 43.3 | 464 | 30.61 | 133.1 |
| D4 (400) | 1.5 | 44.7 | 424 | 31.87 | 122.6 |

| Plant population (* m$^{-2}$) | Weed DW (g m$^{-2}$) | Root DW (g m$^{-2}$) | Total stem field DW (g m$^{-2}$) | Raw bast in stem (%) | Raw bast DW (g m$^{-2}$) |
|-------------------------------|---------------------|---------------------|---------------------------------|---------------------|---------------------|
| P | 0.011 | 0.951 | 0.085 | 0.52 | 0.079 |
| L.s.d | 13.69 | 7.29 | 60.5 | 3.299 | 23.39 |

### Table 6. Leaf chlorophyll concentration (SPAD) and stem thickness of male and female plants at harvest.

| Plant population | Chlorophyll content (SPAD units) | Average stem thickness (mm) | Male Stem thickness (mm) | Female stem thickness (mm) |
|------------------|----------------------------------|-----------------------------|--------------------------|----------------------------|
| D1 (100) | 35.9 | 6.4 | 6.0 | 6.8 |
| D2 (200) | 38.7 | 5.6 | 5.3 | 5.9 |
| D3 (300) | 37.3 | 5.6 | 5.1 | 6.1 |
| D4 (400) | 36.8 | 5.1 | 4.5 | 5.7 |

| Plant population | Chlorophyll content (SPAD units) | Average stem thickness (mm) | Male Stem thickness (mm) | Female stem thickness (mm) |
|------------------|----------------------------------|-----------------------------|--------------------------|----------------------------|
| P | 0.226 | 0.002 | <0.001 | 0.055 |
| L.s.d | 2.74 | 0.626 | 0.64 | 0.85 |

### Table 7. Mean plant heights (mm) at different densities and for male and female plants over a 28 day period.

| Density | 25 | 32 | 39 | 46 | 53 |
|---------|----|----|----|----|----|
| D1 | 369 | 881 | 1126 | 1191 | 1201 |
| D2 | 399 | 869 | 1088 | 1132 | 1140 |
| D3 | 443 | 868 | 1049 | 1094 | 1098 |
| D4 | 332 | 854 | 1034 | 1103 | 1112 |
| P | 0.058 | 0.918 | 0.183 | 0.054 | 0.042 |

| Density | 25 | 32 | 39 | 46 | 53 |
|---------|----|----|----|----|----|
| SEX | | | | | |
| Female | 385 | 778 | 1005 | 1078 | 1090 |
| Male | 436 | 958 | 1143 | 1182 | 1185 |
| P | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

| Density | 25 | 32 | 39 | 46 | 53 |
|---------|----|----|----|----|----|
| L.s.d | 57.2 | 76 | 91 | 75.3 | 74.9 |

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densities, male plants were significantly taller than females at each sampling date. Height at harvest was lower at higher plant densities; an effect described by [2,17] and explained as the result of interplant competition. This result is despite the fact that at early growth, higher populations produced taller plants. This earlier effect is probably caused by the shade avoidance syndrome [9] causing elongation of stems where light competition is greatest, in this case, at high densities. Once maturity is reached, however, it is probable that self-thinning and competition stress result in shorter plants in high densities than at low densities. The effect of density within the range in this research did not show a profound effect on crop maturity (Figure 6), as the crop under different densities matured concurrently. Research evaluating several different harvest times for tropical hemp to ascertain optimal planting/harvesting window is suggested.

Figure 6. Planting date 1 (1st Oct) at full flowering. Planting density of 200 and 100 plants m\(^{-2}\) on the left and right respectively.

Raw bast yields
A significant difference in raw bast fibre dry weight yield was observed between D1 and D3 (Table 5). Bast yields increased significantly in response to increasing density to D3, then dropping off slightly at D4. D1 yielded on average 102.8 g m\(^{-2}\) raw bast in comparison to 133.1 g m\(^{-2}\) at D3. The percentage of bast fibre per unit weight of straw ranged from 29–32% but did not differ significantly between plant densities, although a slightly higher raw fibre percentage in D4 hints at a possible density effect (Table 5). The relationship between increasing proportion of stem weight as bast fibre and increased sowing density was not apparent in this experiment, despite other studies such as [5] that indicated this. Significantly greater fibre yields at D3 than D1, and the general trend towards greater yields in the higher population densities, supports [6] recommendation of 300–500 plants m\(^{-2}\) for optimal fibre yields. Their and our results are contrary to other research findings [9] where density did not greatly affect fibre yields.

No difference in root weights between densities implied that all significant changes influenced by plant population were in the aerial plant parts. Soil compaction may have resulted in small root systems for all treatments. Readily available water and ample nutrients may have minimised the need for root expansion. Stem yields across all densities ranged from 3.8–4.6 t ha\(^{-1}\), although this estimate does not necessarily represent likely commercial yields since conventional harvesting would not recover as much stem as hand harvesting. These yields are very low in comparison to estimates of the average European yields of 6–9 t stem ha\(^{-1}\) and yield models have indicated that potential yields of up to 17 t ha\(^{-1}\) are possible with industrial hemp [18,19]. These researchers also suggest that even 20 t stem ha\(^{-1}\) is feasible. Low fibre yield in the trials with the current variety is due to photo-period sensitivity of this variety as the crop tends to flower when the day length is less than 13 hours 30 minutes [13]. Early flowering results in precocious plant maturity (~60 days), and a consequential short plant stature (~2 m), unlike the European cultivars where plant heights are 3 m or more. Extending the day length by one extra hour in other trials delayed flowering of industrial hemp at this site [13]. Total plant dry weight data were not taken for the entire plot in this trial due to the small size of the samples. For this reason it is very difficult to accurately determine radiation use efficiency (RUE), water use efficiency (WUE) and nitrogen use efficiency (NUE). As above-ground biomass decreases in industrial hemp due to senescence, as harvest approaches, these efficiency parameters also decrease as described by [15].

Other factors
By day 53, plants had fully flowered, grain-fill was advanced in most females, and males had mostly senesced, resulting in a cessation of growth across the plots. This was so for both planting dates and the final harvest was conducted considerably later in the developmental stage of the plants than what would be acceptable for a fibre crop. The duration of the crop (63 days from planting to harvest) was, as a result of the early maturity, much shorter than conventionally grown European hemp. Although plants at high planting densities have been observed to flower later than plants sown at lower densities [1] this parameter was not quantified comprehensively in this experiment, although no obvious visual relationship between planting density and flowering time was observed (Figure 6).

Ample nitrogen applications during crop development (120 kg ha\(^{-1}\) in total) may have been responsible for the lack of variation in leaf chlorophyll content across treatments. Some disease, mainly Sclerotium rolfsii, was present in the crop; it did not express in patches but was rather uniformly spread across all plots. Wetter weather may have increased the incidence of this disease in the second planting, towards the end of the trial.
Shortly after flowering, the crop experienced an infestation of budworm (*Helicoverpa* spp.) and green vegetable bug (*Nezara viridula*), which, whilst having seemingly little effect on fibre hemp at the late stage of infestation in this trial, may be detrimental to grain and seed cultivation.

Conclusions

Overall yields of stem (3.8–4.7 t ha⁻¹) were well below the reported range for cultivation of hemp in Europe and North America (up to 17 t ha⁻¹). The experiment, however, did show that certain consistencies in a crop may be expected if a suitable hemp fibre cultivar were to be developed. The plants matured quickly as a result of the hastening effect on growth of short day lengths on flowering and maturity (research was conducted at latitude 24.9°S).

The data suggest that an optimal planting density for the BundyGem variety in a ferrosol at the trial site is 300 plants m⁻². This density produced greater raw fibre yields and qualities associated with harvest of good fibre hemp such as thin stalks than did lower planting densities. The relationship between increasing proportion of stem weight as fibre and increased sowing density was not apparent in this experiment. However, stem thickness and plant height were inversely proportional to initial plant density. Weed suppression was also clearly affected by plant population as plant populations of 100 plants m⁻² resulted in significantly greater weed biomass than did higher plant densities.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

| Authors’ contributions | JH | SPB | DJM |
|------------------------|----|-----|-----|
| Research concept and design | ✓ | ✓ | ✓ |
| Collection and/or assembly of data | ✓ | ✓ | ✓ |
| Data analysis and interpretation | ✓ | ✓ | ✓ |
| Writing the article | ✓ | ✓ | ✓ |
| Critical revision of the article | ✓ | ✓ | ✓ |
| Final approval of article | ✓ | ✓ | ✓ |
| Statistical analysis | ✓ | ✓ | ✓ |

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References

1. Amaducci S, Colauzzi M, Bellocci G and Venturi G. Modelling post-emergent hemp phenology (*Cannabis sativa* L.): Theory and evaluation. *European Journal of Agronomy*. 2008; 28:90-102. | Article

2. Amaducci S, Zatta A, Pelatelli F and Venturi G. Influence of agronomic factors on yield and quality of hemp (*Cannabis sativa* L.) fibre and implication for an innovative production system. *Field Crops Research*. 2008; 107:161-169. | Article

3. Anonymous. *Industrial hemp variety and seeding rate trial 2009.*

4. Bassetti P, koneman M, Mediavilla V and Scheid-slembruck L. Optimisation of nutrient fertilisation and seed density in hemp crop. *Agraforschung.* 1998; S:241-244. | Article

5. Bennett S J, Snell R and Wright D. Effect of variety, seed rate and time of cutting on fibre yield of dew-retted hemp. *Industrial Crops and Products.* 2006; 24:79-86. | Article

6. Bosa C I and Karus M. The cultivation of hemp: botany, varieties, cultivation and harvesting. *Sebastopol, Hemptech. California.* 386. | Book

7. BOM 2012. *Climate statistics for Australian location-Bundaberg.* 1998.

8. Bullard M. J, Mustill S. J, Carver, P and Nixon P. M. I. Yield improvements through modification of planting density and harvest frequency in short rotation coppice *Salix* spp.–2. Resource capture and use in two morphologically diverse varieties. *Biomass and Bioenergy.* 2002; 22:27-39. | Article

9. Burczyk H., Grabowska L., Strybe M and Konczewicz W. Effect of sowing density and date of harvest on yields of industrial hemp. *Journal of Natural Fibers.* 2009; 6:204-218. | Article

10. Cerdan PD and Chory J. Regulation of flowering time by light quality. *Nature.* 2003; 423:881-5. | Article | PubMed

11. Hall J, Bhattarai S.P and Midmore D. J. Review of flowering control in industrial hemp. *Journal of Natural Fibers.* 2012; 9:23-36. | Article

12. Hall J, Bhattarai S. P and Midmore D. J. The effects of different sowing times on maturity rates, biomass, and plant growth of industrial fiber hemp. *Journal of Natural Fibers.* 2013; 10:40-50. | Article

13. Hall J, Bhattarai S. P and Midmore D.J. The effects of photoperiod on phenological development and yields of industrial hemp. *Journal of Natural Fibers.* 2013.

14. Lisson S. N and Mendham N. J. Cultivar, sowing date and plant density studies of fibre hemp (*Cannabis sativa* L.) in Tasmania. *Australasian Journal of Experimental Agriculture.* 2000; 40:975-986. | Article

15. Meijer W. J. M, Van der Werf H. M. G, Mathijssen E. W. J. M and Van den Brink P. W. M. Constraints to dry matter production in fibre hemp (*Cannabis sativa* L.). *European Journal of Agronomy.* 1995; 4:109-117. | Article

16. Mosjidis J. A and Wehtje G. Weed control in sunn hemp and its ability to suppress weed growth. *Crop Protection.* 2011; 30:70-73. | Article

17. Ranalli P. *Agronomical and physiological advances in hemp crops.* In: *RANALLI, P. (ed.) Advances in Hemp Research.* New York: Food Products Press. 1999. | Book

18. Struik P. C, Amaducci S, Bullard M. J, Stutterheim N. C, Venturi G and Cromack H. T. H. *Agronomy of fibre hemp (Cannabis sativa L.)* in Europe. *Industrial Crops and Products.* 2000; 11:107-118. | Article

19. Van der Werf H. M. G, Mathijssen E. W. J. M and Haverkort A. J. Crop physiology of *Cannabis sativa* L.: A simulation study of potential yield of hemp in Northwest Europe. In: *RANALLI, P. (ed.) Advances in Hemp Research.* New York: Food Products Press. 1996.

20. Van der Werf H. M. G, Wijhuijzen M and De Schutter J. A. A. Plant density and self-thinning affect yield and quality of fibre hemp (*Cannabis sativa* L.). *Field Crops Research.* 1995; 40:153-164. | Article

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