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final report

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Improving productivity of rundown sown grass pastures

Volume 4: Improving reliability of establishing legumes into existing grass pastures

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Executive summary

Background:

A major constraint to the successful incorporation of legumes into existing sown grass pastures is the lack of establishment reliability. Legumes like desmanthus, Caatinga stylo, leucaena and medics have been shown to be well adapted and productive in the Brigalow Belt bio-region (Volume 3 of this report) and have been available to graziers for 20+ years. There have been many tons of legume seed sold over multiple decades to graziers in the Brigalow Belt, but very few pastures with a meaningful amount of legumes present to show for the investment. Graziers involved in focus group discussions identified poor establishment as one of the major constraints to the use of legumes with existing sown grass pastures (Peck *et al.*, 2011).

Although good establishment is recognised as critical to the long term productivity and persistence of pasture legumes, most producers use low-cost and low-reliability establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire) or one-pass cultivation where seed is sown at the same time or severe soil disturbance and a rough seed bed behind a blade plough used for controlling woody regrowth (Peck *et al.*, 2011). These techniques of introducing legumes have been considered successful in many years in monsoonal areas which have a much higher chance of germinating rain with follow up rain shortly after and less competitive native grasses on less fertile soils but have been woefully inadequate in the vast majority of years with competitive sown grass pastures on fertile soils in the sub-tropics.

Although good establishment is recognised as critical, many producers don't think they can afford to use more expensive establishment techniques and defer grazing to allow legume establishment. A focus on establishment difficulties and negative short term economic returns by producers needs to be balanced with the opportunities of higher production of legume grass pastures over the long term as demonstrated by research. Despite the opinion expressed by graziers during focus group discussions, economic analysis suggests that spending more money on legume establishment in this environment will provide better returns, especially compared to techniques that have been failing graziers for decades (Peck *et al.*, 2011).

The un-reliable results from commercial sowings of legumes into existing sown grass pastures has led to more reliable establishment techniques being a research priority for this project. The aims of this component of the project were to quantify the impacts of using better agronomic practices for establishing legumes into existing grass pastures.

Project overview:

Sixteen trials were conducted to test different aspects of establishing legumes into existing grass pastures. The trials conducted as part of this project were:

- Two fallow moisture storage trials. These trials aimed to determine how far buffel grass roots extract water into a fallowed strip. Fallowed strips are seen as a way of improving reliability of establishment while reducing overall costs and permitting some grazing during preparation.
- Two seeding rate trials. These trials tested whether increasing seeding rate results in higher numbers of legume plants establishing.
- Six fallowing, seed bed preparation and post-emergence weed control trials. These trials aimed to test the impact of using agronomic practices typically used in the grain industry on legume establishment.

- Six rate of legume spread trials. These trials aim to determine how quickly Caatinga stylo and desmanthus spread into existing grass pastures if they are established in strips.

Major conclusions:

Establishment trials conducted as part of this project have shown that establishing small seeded legumes like desmanthus and Caatinga stylo can be a lot more reliable if good agronomic practices are used. Key principles or considerations for reliable legume establishment in existing grass pastures are:

- Legume seedling access to moisture and other nutrients.
- Good seed to soil contact.
- Establishing legumes in strips or across whole paddocks.

Legume seedlings need access to moisture (and other nutrients)

Legume seedlings need good moisture supply for rapid early growth to be large enough to cope with the stresses of dry seasonal conditions and winter to limit mortality as well as produce forage for livestock. In particular there needs to be enough water when seedlings are very small to survive from the first germinating rain through to when follow up rain is received.

The supply of moisture can come from stored soil moisture and/or rainfall. The available water can either be used by the legume seedlings or through competing plants like the existing grass pasture or other weeds. Reliable legume establishment relies on more water being available more often and more of the available water being used to support legume growth.

- Fallowing improves legume establishment. Fallowing to store soil moisture, reduce the soil seed bank, and reduce competition from both grass and weeds is critical to minimise the impacts of the episodic rainfall events that are typical of the Brigalow Belt bio-region, thereby reducing seedling mortality rates. Stored soil moisture via fallowing allows seedlings to survive and grow even in dry seasons. Across all six trial sites, increasing fallow period improved legume establishment. The best legume establishment with the highest plant numbers and dry matter production occurred in long fallow period (9-12months) treatments.
- Rainfall. Follow-up rainfall is critical for legume seedling survival; stored soil moisture increases the period that legumes can grow before being moisture stressed. Timing of sowing is therefore critical to maximise the chance of follow up rainfall. For most of Queensland's sub-tropics, the highest rainfall months are January and February, which often also coincide with decreasing temperatures which reduces water demand by plants and evaporation.
- Grass and weed competition. Competition from existing grasses and weeds is often the major influence on high seedling mortality. Controlling competition from the existing grass is best achieved through fallows. The results from the establishment trials showed that the longer the fallow period, the greater the control of both the existing pasture but also the soil seed bank. Within the same fallow period treatments, there can be a significant improvement in legume growth through controlling competition from re-colonising grasses and weeds via post emergence herbicides.

The general recommendations to balance soil water storage, follow up rainfall and competition when establishing legumes into existing grass pastures for the in-land sub-tropics of Queensland from our trial results (and other trials) are:

- Plant in January/February as this is the time of the year with highest rainfall and the greatest chance of follow up rain. Adjust to planting earlier if there is good stored moisture and/or the seasonal outlook is for a wet summer. Also plant earlier if sowing in high frost incidence locations (e.g. on the Darling Downs in frost hollows).
- Store sufficient soil water through fallowing.
  - Establishing in strips. In most districts on better soils that can store significant amounts of water, this is likely to mean long fallows of 9-12 month duration to maximise legume growth within the strips to maximise seed set and spread in subsequent years. In wetter years or wetter districts or soils with lower water holding capacity this can be reduced to medium length fallows of 3-6months.
  - Planting whole paddocks. If planting the whole paddock there is a trade-off between grass and legume growth to maintain a balance in pasture composition. Medium length fallows of 3-6 months will allow grass to re-colonise from some remaining tillers or tussocks and from the soil seed bank.
- Control grass and weed competition. The most effective way to reduce competition from existing plants (grass and weeds), as well as reducing the soil seed bank through control of germinating seedlings is via fallowing. Where grass and weed loads are high, spraying with post emergence herbicides should result in significantly more legume growth.

Good seed to soil contact

Practices that increase soil to seed contact when sowing can improve legume germination and growth. In the trials conducted in this project drilling seed produced better legume density than broadcasting seed where it improved seed to soil contact, for example:

- Soil types where the soil surface is firm, that is crusting, hard setting or firm soil surfaces typical of loamy soils.
- Zero tillage compared to cultivated fallows or cultivated planting operations.
- Very dense pasture cover which reduces the chance of broadcast seeds contacting the soil surface.

Drilling produced no benefit on self-mulching clay soils without excessive pasture cover. Drilling produced negative results where seed was sown too deep. Drilling of small seeded legumes should not be attempted unless planting equipment allows very good control of sowing depth.

Establishing legumes in strips

Pastures require both grass and legumes to be highly productive in the long term. If a paddock already has good grass pastures, graziers are reluctant to kill them and forego grazing for a period to establish a legume. The dry matter (DM) production from the trials in this project suggest that establishing legumes in strips within existing grass pastures offers the compromise between cost, lost grazing and reliable legume establishment. At the trial where DM production was measured at 12 months, the long fallows produced four to five times more legume DM than the medium fallows. Therefore if 20 – 25% of a paddock (e.g. 5m fallowed strip on 20-25m centres) was established to legumes in long fallow (9-12months) strips, it is capable of producing as much legume per hectare as ploughing or spraying out the whole paddock for a medium length fallow (3-6months).

Fallowed strips need to be wide enough to allow soil moisture storage, that is wide enough that the grass roots do not extract the water by growing in from the edge during the fallow. To maximise moisture storage to depth in the soil requires fallow strips to be >6m wide. Competition from the grass strips is greatest out to approximately 1m into the fallowed strips, therefore even in higher rainfall environments with a high likelihood of follow up rain require strips >2m.

Given the considerations above it is recommended that strips be >3m wide in the wetter parts of the Brigalow belt bio-region (e.g. the inland Burnett catchment, Callide district) as a minimum. In drier districts further inland, fallowed strips would need to be wider to allow for fallow moisture storage and the reduced likelihood of in-crop rainfall after sowing legumes. Strips in inland districts should be >6m wide.

Recommendations:

Poor establishment is the most common reason for failure of pasture legumes in existing commercial grass pastures, however the most commonly used methods by graziers are low cost and low reliability. Fallowing to store soil moisture and control competition from the existing grass pasture improve establishment. Greater control of competition through the use of post-emergence herbicides (e.g. Spinnaker) can improve seedling survival and therefore establishment success. Establishing legumes in long fallowed strips (9-12 month fallows) may be able to achieve equally high legume dry matter production per hectare with higher reliability than medium length fallows (3-6 months) over the whole paddock.

Plot trials in this project have shown that dramatically better and more reliable establishment of small seeded legume into existing sown grass pastures is achievable through using agronomic practices that are commonly used by the grains industry (and graziers when establishing leucaena). Industry needs to adopt more reliable establishment techniques when introducing legumes into existing grass pastures for them to realise their potential to improve productivity and economic returns in the sub-tropics. The challenge for future participatory research and extension is to take the principles developed from the plot trial results and adapt them to the paddock scale and commercial equipment.

Acknowledgements

The authors wish to acknowledge the support of several landholders who were very generous in volunteering their properties, time and machinery in hosting research trials for studying establishing legumes into existing grass pastures. These trials have run over several years and relied on the input and maintenance of the graziers hosting the trial sites. Without their support the trials would not have been possible. Graziers who hosted research trials were:

- Gina and Alistair Mace, “Malanga”, Nindigully
- Dennis and Barbara Cormack, “Juandah Valley”, Wandoan
- Steve and Emily Wilkins, “Kioma”, Goondiwindi
- Alan and Joy Gath, “Amaroo”, Chinchilla
- Paul and Maria Keys, “Toston”, Condamine

The authors would also like to extend thanks to Jenny Foley and Mark Foley of the Department of Natural Resources and Mines for both providing access to an EM38 conductivity meter and for support in trial design and data interpretation. Gabriela Borgognone, Kerry Bell, Michael Mumford and David Mayer of the department’s biometry staff are also acknowledged for their support in the processing and interpretation of the large amounts of data collected within the trials.

Final report outline

The final report has been organised in volumes due to the project having three components, each with multiple activities. The report has four volumes, volume one reports on the main results across the whole project with more detail being provided in the following volumes on each of the three components of the project. The titles of the four volumes are:

Volume 1: Project overview, key findings and recommendations.

Volume 2: Improving understanding and testing mitigation options with industry.

Volume 3: Persistence and comparative productivity of legumes in sown grass pastures.

Volume 4: Improving reliability of establishing legumes into existing grass pastures.

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1 Background

A major constraint to the successful incorporation of legumes into existing sown grass pastures is the lack of establishment reliability.

Legumes like desmanthus and Caatinga stylo have been shown to be well adapted and productive in the Brigalow Belt bio-region (Volume 3 of this report) and have been available to graziers for 20+ years. There have been many tons of legume seed sold over multiple decades to graziers in the Brigalow Belt, but there are very few pastures with a meaningful amount of legumes present to show for the investment. Graziers involved in focus group discussions identified poor establishment as one of the major constraints to the use of legumes with existing sown grass pastures (Peck *et al.*, 2012; Peck *et al.*, 2011). Many of the graziers reported seeing either no legume plants or low legume densities before the legumes died out in the few years. In both commercial paddocks and grazing trials, there are many instances where low legume numbers recorded shortly after establishment have carried through to low legume densities 15 years later (Volume 3 of this report).

The poor establishment of legumes into existing sown grass pastures in the Brigalow Belt bio-region is in contrast to the recommendations developed for stylo's and other hardy legumes in more monsoonal environments with native pastures. Commercially, pasture legumes have not established reliably in existing sown grass pastures or competitive native pastures in the sub-tropics. In the black spear grass zone of central and southern Queensland, surface sowing legumes into existing native grass pastures without controlling the grass has been shown to be unreliable with a 80% failure rate (Cook *et al.*, 1992); it is likely that sowing into competitive sown grass pastures like buffel grass in the lower rainfall Brigalow Belt bio-region have even higher failure rates.

The amount and distribution of rainfall combined with the competition from the existing pasture are the likely explanation for the differences in success in establishing legumes in the more monsoonal northern native pastures compared to the sown grass pastures (mainly buffel grass) in the sub-tropics. The likelihood of germinating rain combined with follow up rain before seedlings die is higher in the monsoonal areas than in the inland sub-tropics. Climate classification based on a plant growth model identified the Brigalow Belt bio-region as being unique in the world, with the main distinguishing feature of the climate being that it is relatively seasonally uniform and moisture limited throughout the year (Hutchinson *et al.*, 2005; Hutchinson, 1992). The pasture growth over the growing season is characterised by multiple growth spurts with rapid growth after rain, followed by moisture stress before additional rain is received.

Additional to the climate, the competition from sown grass pastures on fertile soils is much higher than that of native pastures on infertile soil; with much higher pasture biomass being produced per year (Lambert and Graham, 1996). Survival and growth of seedlings is severely influenced by competition from existing pasture plants and weeds. Competition from existing vegetation and weeds is often the major influence on high seedling mortality. It is not that competition *per se* that kills seedlings; rather competition from existing vegetation may restrict growth to such an extent that seedlings subsequently die from moisture stress, temperature stress or acute nutrient deficiency. Survival depends on plant size when stress is encountered. Well established pasture grasses with large root systems are clearly better able to cope with nutrient and moisture stress then establishing legume seedlings (Cook *et al.*, 1993a; Cook *et al.*, 1993b).

Fallowing to store soil moisture is crucial to the success of dryland grain cropping in the Brigalow Belt climate (Hutchinson, 1992; Hutchinson *et al.*, 2005). Fallowing, sowing and weed control methods similar to those used in dry land cropping which control plant competition and facilitate soil moisture storage can dramatically reduce the effects of variable rainfall on pasture establishment (Cook *et al.*, 1993a; Cook *et al.*, 1993b; Dalzell *et al.*, 2006). Only when establishing leucaena, does industry routinely use "cropping methods" for establishment (Peck *et al.*, 2011). The willingness to use improved agronomy when establishing leucaena probably reflects that it is a more mature technology, it does not increase in density over time (if well managed) and the perception that it's persistence and productivity warrant the additional effort and cost.

Although good establishment is recognised as critical to the long term productivity and persistence of pasture legumes, most producers use low-cost and low-reliability establishment techniques such as broadcasting out of planes after either no or minimal pasture disturbance (e.g. fire) or one-pass cultivation where seed is sown at the same time or severe soil disturbance and a rough seed bed behind a blade plough used for controlling woody regrowth (Peck *et al.*, 2011).

Although good establishment is recognised as being critical, many producers don't think they can afford to use more expensive establishment techniques and defer grazing to allow establishment. A focus on establishment difficulties and negative short term economic returns by producers needs to be balanced with the opportunities of higher production of legume grass pastures over the long term demonstrated by research. Despite the opinion expressed by graziers during focus group discussions, economic analysis suggests that spending more money on legume establishment in this environment will provide better returns, especially compared to techniques that have been failing graziers for decades (Peck *et al.*, 2011).

The un-reliable results from commercial sowings of legumes into existing sown grass pastures has led to more reliable establishment techniques being a research priority for this project. Sixteen trials were conducted to test different aspects of establishing legumes into existing grass pastures. The locations of the trials are shown in Fig. 1. The trials conducted as part of this project were:

- Two fallow moisture storage trials. These trials aimed to determine how far buffel grass roots extract water into a fallowed strip. Fallowed strips (as opposed to fallowing an entire paddock) are seen as a way of improving reliability of establishment while reducing overall costs. If fallowed strips are to be used a key question is how wide do strips need to be to allow soil moisture storage.
- Two seeding rate trials. These trials tested whether increasing seeding rate facilitates better establishment.
- Six fallowing, seed bed preparation and post-emergence weed control trials. These trials aimed to test the impact of using agronomic practices typically used in the grain industry on legume establishment.
- Six rate of legume spread trials. These trials aim to determine how quickly Caatinga stylo and desmanthus spread into existing grass pastures if they are established in strips.

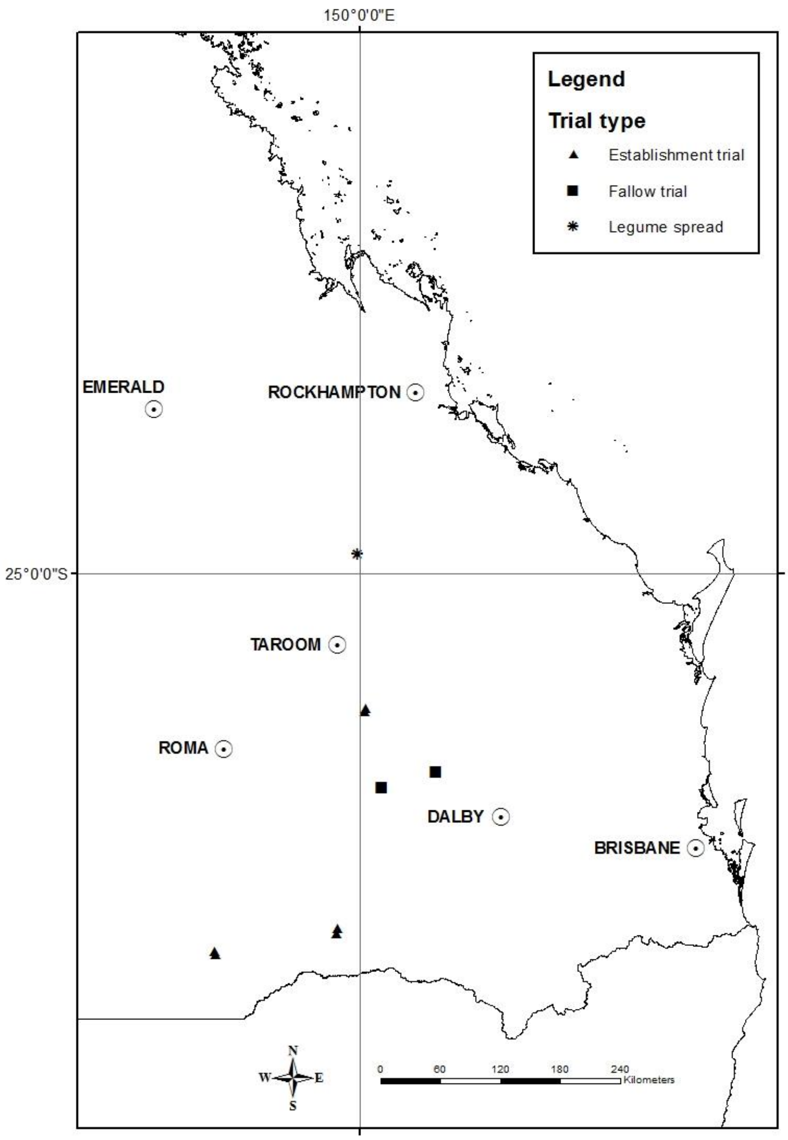

Fig. 1: Location of legume establishment trials.

2 Fallow moisture storage trials

2.1 Introduction

Establishing pasture legumes into existing grass pastures is challenging in the sub-tropics as legumes struggle to compete with the existing grass plants for water, nutrients and light. The Brigalow belt bio-region climate is characterised by being moisture limited for plant growth throughout the year with relatively mild winters (Hutchinson, 1992). Dryland grain cropping in this environment relies on clay soils that can store large amounts of soil moisture to reliably reach maturity; by contrast grain cropping in more seasonally wet regions (e.g. Mediterranean climates in southern Australia or more monsoonal environments further north) relies more on in-crop rainfall.

Reliable legume establishment requires adequate moisture being available in most years for legumes to grow rapidly to be large enough to cope with the stresses of frosts, dry seasons (especially winter/spring), grazing and to set seed to enable seedling recruitment in subsequent years. To have enough moisture available for legume seedlings to achieve these growth rates requires control of competition from the existing pastures and stored soil moisture in most years to cope with the lack of follow up rainfall characteristic of the climate in the inland sub-tropical districts of Australia. Fallowing to control weeds and store moisture in the soil has been demonstrated to be a reliable way of establishing legumes either after grain cropping or when renovating pastures (Cook, 2007).

A large proportion of graziers involved in focus group discussions considered ploughing or spraying out whole paddocks to be too expensive in the short term and potentially risky as the grass may take a long time to re-establish (Peck *et al.*, 2011). Fallowed strips may be the compromise that allows good moisture storage and weed control in the strips while reducing up-front costs and allowing grazing of the remaining grass to continue during the fallow period to reduce the loss of income.

If fallowed strips are to be used, a key consideration is how wide the strips need to be to store moisture in the middle of the strip? An alternative description of this question is how far laterally do existing grass pastures growing on the edge of the strip extract moisture into a fallowed strip? This part of the project aimed to answer this question.

2.2 Methodology

Two fallow moisture storage in fallowed strips trials were conducted on two different soil types in southern Queensland. Fallows commenced in November 2011. One trial was located near Chinchilla and the other was near Condamine (Fig. 1).

The Chinchilla trial was conducted on a Brigalow cracking clay and was classified as a Black Vertosol. The Condamine trial was conducted on a loamy surfaced Sodosol, locally referred to as poplar box/ belah soil type. Pastures at both trial sites was dominated by buffel grass.

The trial sites consisted of two treatments of zero tillage (ZT) or cultivated fallowed strips, replicated three times. Zero tillage treatments only used herbicides to control grass and weeds to maintain a bare fallow. Cultivation treatments were initially cultivated to establish the bare fallow; herbicides were subsequently used after some rainfall events to control emerging weeds. The bare fallows allowed the plots to progressively store soil moisture with each rainfall event, whereas the grass strips used moisture between rainfall events.

Apparent electrical conductivity (ECa) readings were taken on 5 occasions throughout the duration of the fallow period, as moisture levels accumulated, using an EM38 ground conductivity meter to estimate changes in soil moisture. These measurements were recorded every 50cm along 10 m, permanently located transects that commenced 2.5m into the grass and continued 7.5m into the fallowed strips. Within each plot, 4 permanent transect lines were measured at each recording period.

Soil conductance varies with soil texture, salinity and moisture with wetter soils having higher conductance. Because the transects were permanently located and the trial sites had reasonably uniform conductance patterns across transects and replicates, recorded differences in measured conductance are primarily attributable to differences in soil moisture.

2.3 Results

Soil conductance along transects from grass into fallowed strips at the Chinchilla trial site, 12 months after the commencement of fallows is shown in Fig. 2; Condamine results, measured 19 months after the commencement of fallows are shown in Fig. 3. These two recording periods have been chosen for analyses and presentation as they correspond with periods of peak soil moisture storage within the fallowed strips and thus demonstrate the greatest contrasts in conductivity between readings taken within the fallowed strip and readings taken within the grass inter-row.

For the recording periods presented, at both sites there was a rapid increase in soil conductance along the length of the transect, commencing in grass pasture and moving into the fallowed strips. The higher soil conductance in the fallowed plots is due to higher soil moisture levels (see discussion). Soil conductance reached a maximum at both trial sites at between 2.5-3.5m into the fallowed strips across the different EM38 measurements. The greatest rate of change in soil conductance occurred from the edge of the grass strip to between 1-1.5m into the fallowed strip.

At Chinchilla there was significantly higher soil conductance in the zero-tillage fallows than in the cultivated fallows. At Condamine there was no difference between treatments.

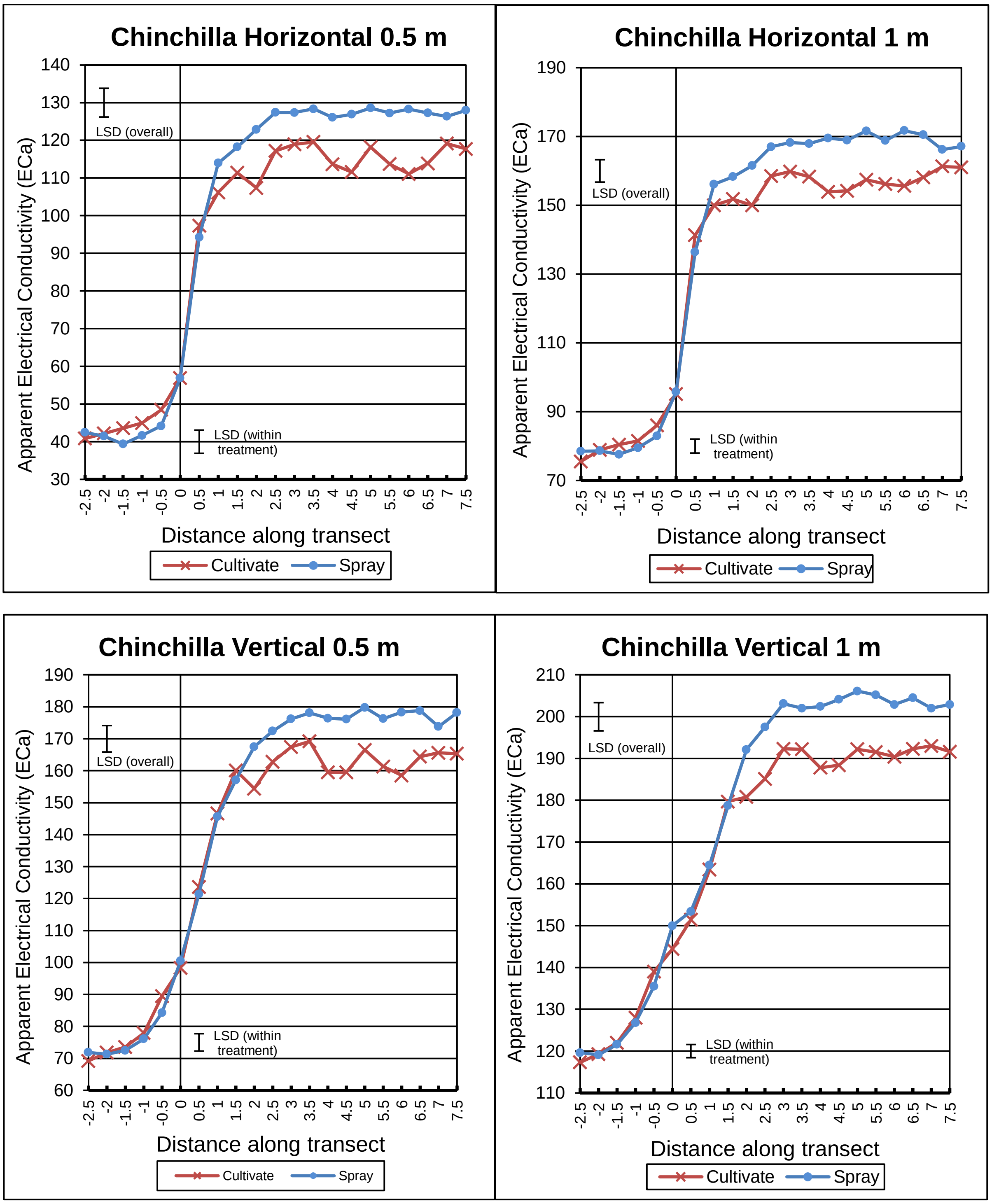

Fig. 2: Mean apparent electrical conductivity (ECa) for spray and cultivation fallow treatments measured at the Chinchilla fallow trial site as measured via EM38. Data from both the 0.5m and 1m coils, in both the horizontal and vertical positions is presented. The line at zero on the x-axis represents the transition from grass (negative numbers) to fallowed strips (positive numbers). The two LSD bars describe the significant differences for within treatments and comparisons across both treatments.

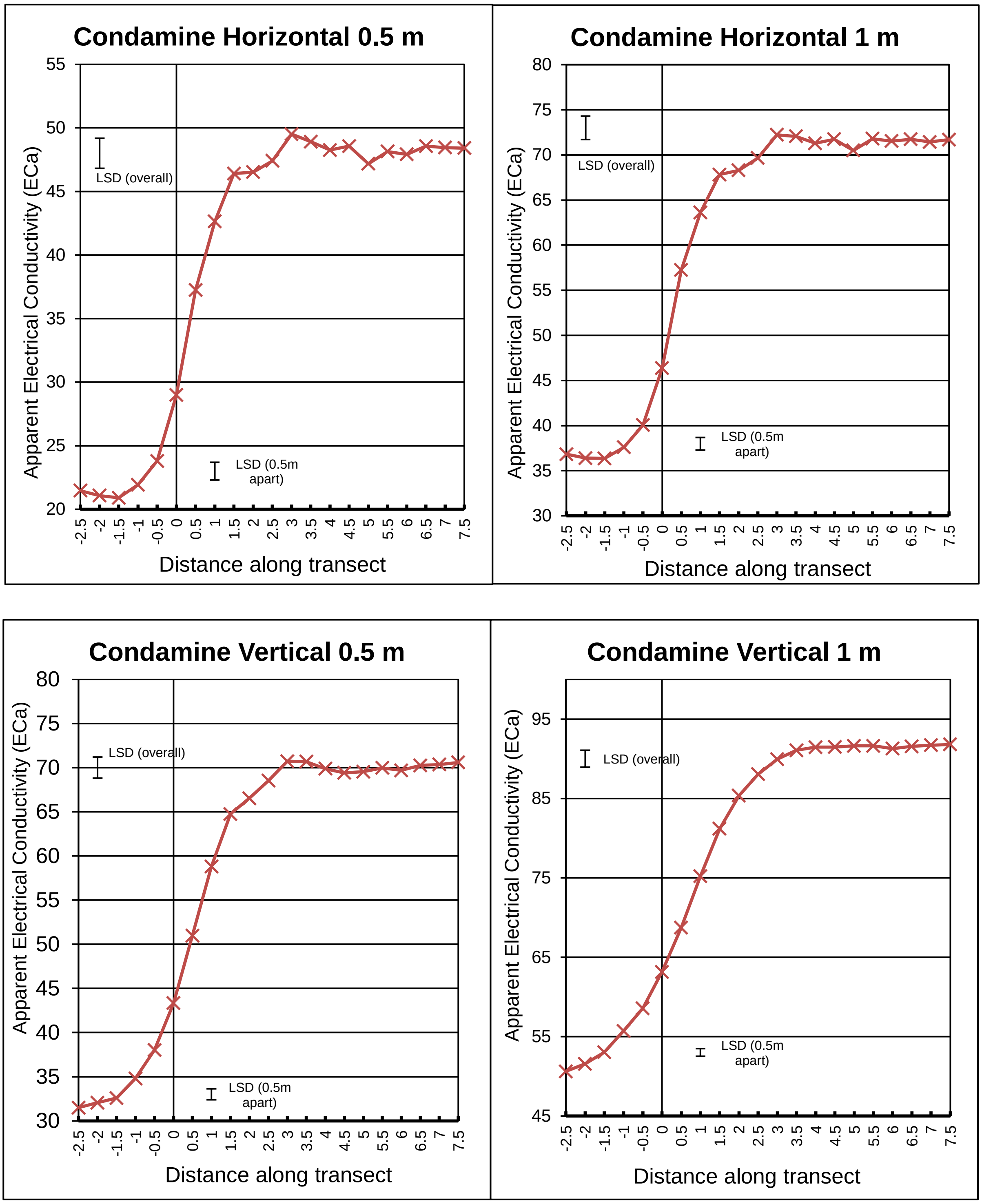

Fig. 3: Mean apparent electrical conductivity (ECa) measured at the Toston fallow trial site as measured via EM38. Data from both the 0.5m and 1m coil spacings, in both the horizontal and vertical positions is presented. The line at intersecting zero on the x-axis represents the transition from grass (negative numbers) to bare fallow (positive numbers).No significant differences were found between spray and cultivation treatments and thus data has been combined for presentation. The two LSD bars describe the significant differences between immediately adjacent values (LSD (0.5m apart)) and comparisons across the full spectrum of the transect (LSD (overall)).

2.4 Discussion

At both trial sites there was a very rapid increase in soil conductance and therefore soil moisture levels when moving along the transects from the grass into the fallowed strips. The EM38 coil spacing's measure different depths of soil:

- Horizontal 0.5m measures conductance to approximately 37.5cm depth.
- Horizontal 1.0m measures conductance to approximately 75cm depth.
- Vertical 0.5m measures conductance to approximately 75cm depth.
- Vertical 1.0m measures conductance to approximately 150cm depth.

The soil conductance reached a maximum at 3m into the fallowed strips for the vertical 1m coil spacing (i.e. the greatest depth of soil measured). Therefore, to maximise soil water storage to depth in the soil requires strips to be greater than 6m wide. In terms of soil moisture storage the centre of strips of this width would behave similarly to situations in which whole paddocks are fallowed

The greatest rate of change in soil moisture occurred approximately 1-1.5m from the edge of the grass strip out into the fallowed strip. The shallower depths of soil have the most rapid change in soil conductance and therefore soil moisture out to approximately 1m into the fallows. The rate of change then reduces and reaches a maximum at about 2.5m into the fallowed strips. These results align with other trials where:

- Grass grows noticeably better along the edge of fallowed strips due to these grass plants accessing additional moisture and nutrients.
- Legume and weed seedlings have not established for approximately 1m into a fallowed strip at other trial sites (Fig. 4).

Fig. 4: Observed sown grass, legume and weed suppression effect along the edges of a fallowed strip at Wandoan loam legume establishment trial site from grass root lateral incursion into fallow strip approximately two years after the strip was sown with grass and legume.

2.4.1 Strip width recommendations

The different soil conductance patterns from this trial give good guidance for recommendations on the width of fallowed strips required to reliably establish legumes into existing grass pastures. To maximise moisture storage to depth in the soil requires fallow strips to be greater than 6m wide. Competition from the grass strips is greatest out to approximately 1m into the fallowed strips and therefore even in higher rainfall environments with a high likelihood of follow up rain, strips need to be greater than 2m wide.

Given the considerations above it is recommended that strips be greater than 3m wide in the wetter parts of the Brigalow belt bio-region (e.g. the inland Burnett catchment, Callide district) as a minimum. In drier districts further inland, the likelihood of dry weather after legume emergence is greater and total rainfall in the first growing season is likely to be lower, therefore fallowed strips need to be wider to allow for fallow moisture storage in order to mitigate the impacts of dry weather on legume seedling growth. Strips in inland districts should be greater than 6m wide.

3 Increasing seeding rate doesn't overcome grass competition

3.1 Introduction

Although good establishment is recognised as critical to the long term persistence of legumes, many producers don't think they can afford to use more expensive seedbed preparation to allow establishment. Several producers and advisors in the pasture seed industry have suggested that increasing seeding rates, but still sowing with no seed bed preparation, will improve the reliability of establishing legumes into sown grass pastures.

This section reports the results of two legume seeding rate trials that tested the impact of increasing seeding rates on legume establishment.

3.2 Methodology

Two seeding rate trials were established near Wandoan, one on a Brigalow grey clay soil (Grey Vertosol) with a buffel grass pasture, the other on a sandy loam alluvial soil. These trials were co-located with the trials testing the impact of fallows and seed-bed preparation on legume establishment described in Section 4.

ProGardes desmanthus (various *Desmanthus spp.*) was sown on the clay soil, fine-stem stylo (*Stylosanthes guinensis var. intermedia*) was sown on the sandy loam. Both legumes were sown at five seeding rates – 1, 2, 4, 8 and 16 kg seed/ha of bare seed that was inoculated with the commercial inoculant with 4 replicates. Seed sown at both sites was good quality with a mix of readily germinable (soft) and hard seed.

Seed was broadcast into undisturbed grass in February 2013. The trials were not grazed for the remainder of the summer growing season to allow measurement of the legumes. Grazing occurred during winter and early spring to allow measurement of the following summer growing season.

Legume seedlings need to be producing true leaves to be able to be identified which takes about one month's growth after germination. The clay soil trial site also had the native legume *Neptunia sp*. present which is very difficult to identify apart from desmanthus in the seedling stage.

Legume plant numbers were recorded 5 and 9 weeks; 9 and 15 months following germinating rains at both sites. The loam trial site was abandoned after the 15 month recording due to there being no stylo plants recorded. At the clay site recordings were repeated at 23, 25 and 38 months after germinating rains.

3.3 Results

3.3.1 Clay soil trial results

At five weeks after germinating rain, there were increasing desmanthus seedling density with increasing seeding rate (Fig. 5). By week 9, almost all of the seedlings that were measured in the first recording had died (Fig. 6). No desmanthus plants were recorded at nine or fifteen months after sowing. At 23 months after sowing there was a germination event that resulted in some plants surviving. There has been an apparent increase in legume density from the second to third year after sowing, however there is very low legume density across all seeding rates.

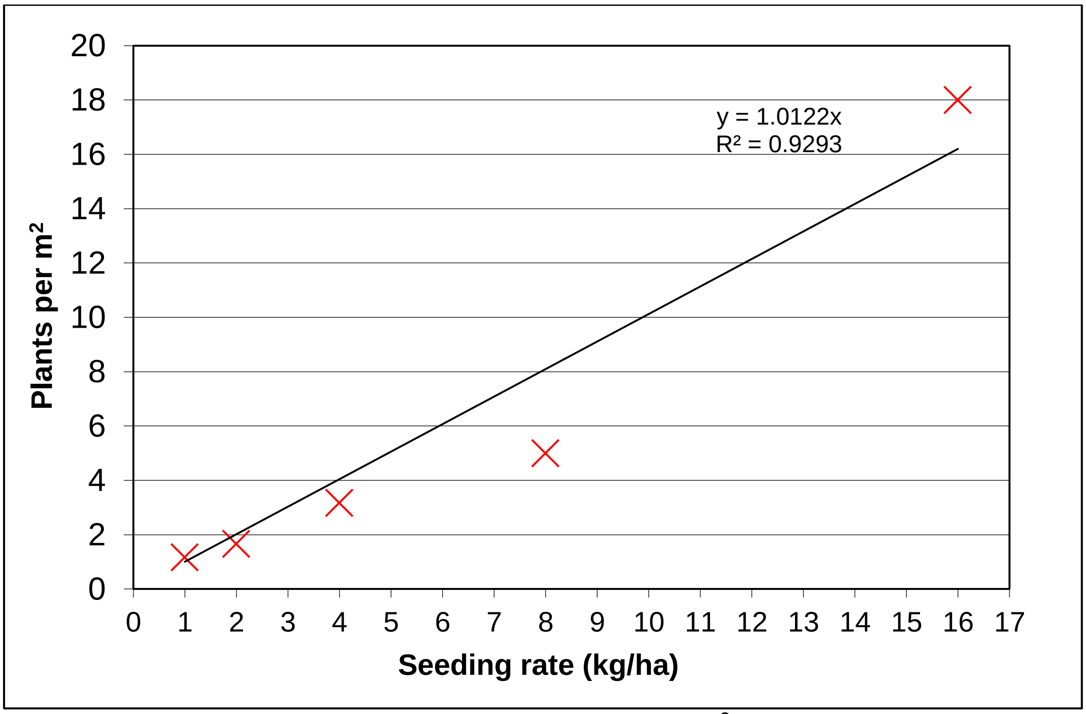

Fig. 5: Recorded desmanthus seedling density (plants/m^2) in response to seeding rates of 1, 2, 4, 8 and 16 kg/ha at five weeks following germinating rain.

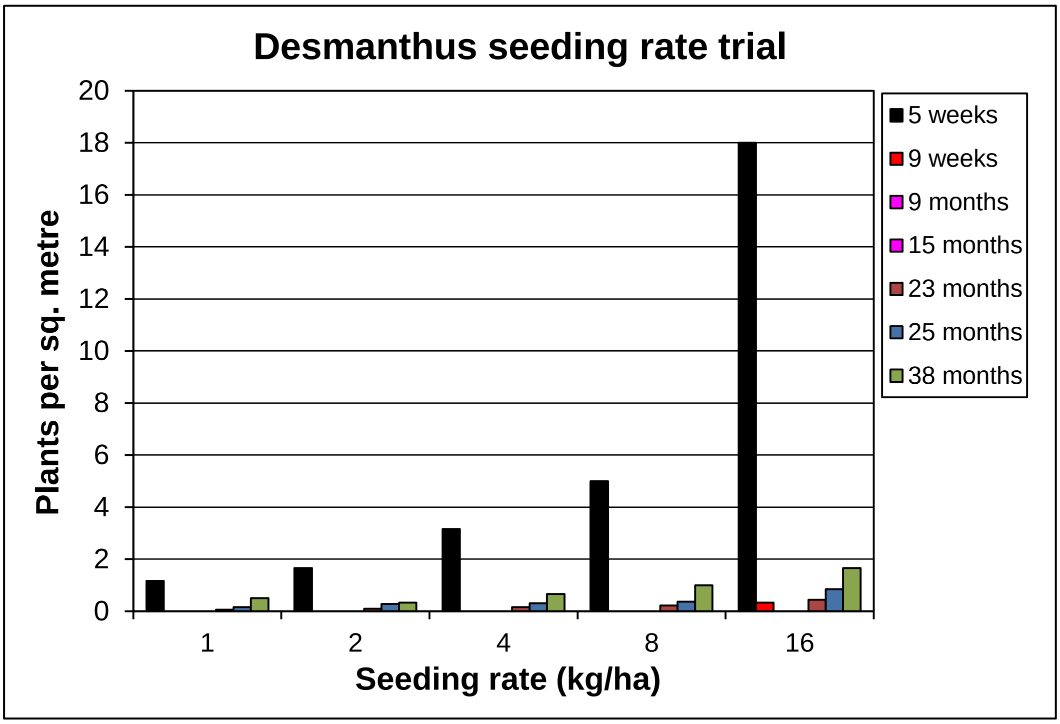

Fig. 6: Recorded desmanthus plant numbers over time in response to seeding rates of 1, 2, 4, 8 and 16 kg/ha. Recordings of plant number were taken at 5 and 9 weeks and 9, 15, 23, 25 and 38 months following germinating rain.

3.3.2 Sandy loam trial results

Fine-stem stylo density compared to seeding rates is shown in Fig. 7. Very low plant numbers were counted at five weeks after germinating rain with all treatments having less than two plants/m^2. The very low plant numbers is due to the seedlings already dying before they were large enough to be identified at 5 weeks. Even lower numbers were recorded at nine weeks after germinating rain. The site was recorded another two times at nine and fifteen months after sowing, but no fine-stem stylo plants were observed. The site was revisited at two years after sowing with no plants being found.

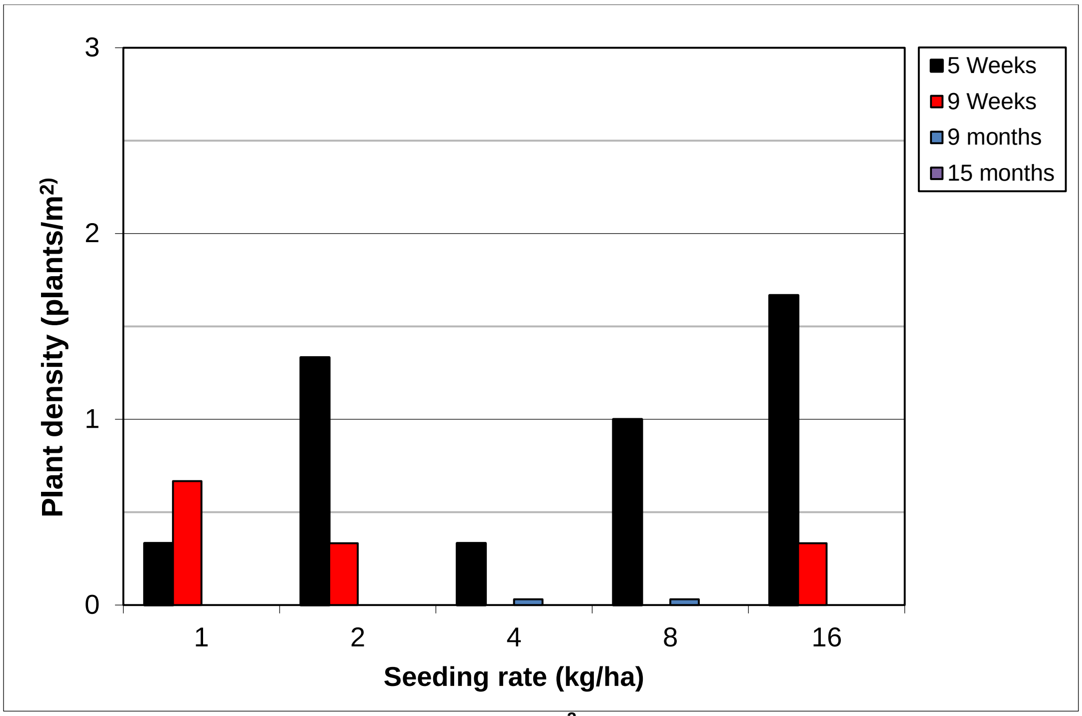

Fig. 7: Fine stem stylo plant density (plant/m^2) in response to seeding rates of 1, 2, 4, 8 and 16 kg/ha at 5 and 9 weeks; and 9 and 15 months following germinating rain.

3.4 Discussion

The trials had a very dry spring and early summer leading up to planting with little grass growth. The site received close to average rainfall in the nine weeks after planting. The following two summers have been below average rainfall. All seeding rates had seedlings five weeks after germinating rain but almost all seedlings had died by nine weeks. None of the seedlings observed at nine weeks were still alive at nine months.

The trials had a very dry spring and early summer leading up to planting with little grass growth (see site seasonal conditions, Table 5). The site received close to average rainfall in the nine weeks after planting. The following two summers were below average rainfall. All seeding rates produced seedlings five weeks after germinating rain (Fig. 6 and Fig. 7). At the desmanthus site, seedling numbers at five weeks were linearly related to seeding rate (R^2=0.92,
Fig. 5). Despite this, almost all seedlings had died by nine weeks and of the few seedlings that had survived to nine weeks, none were still alive at nine months.

Seed that was sown had good levels of hard seed with some of the desmanthus seed managing to germinate and survive in subsequent years; however no seedlings of fine-stem stylo were observed in subsequent years. Even with the germination and survival of desmanthus from the hard seed, by 38 months after sowing no seeding rate had adequate plant numbers to contribute measurably to pasture nitrogen supplies or animal dietary protein (>4 plants/m^2). If continuous grazing was imposed on such a low density of small desmanthus plants in commercial paddocks it is likely that individual plants would be heavily grazed and would set minimal amounts of seed.

These results demonstrate that increasing seeding rate and planting directly into existing grass pastures without controlling grass competition is an unreliable approach to improving legume establishment into buffel grass pastures in inland areas of Queensland. Better agronomic approaches such as controlling competition from the existing pasture and storing soil moisture prior to planting are much more likely to improve the reliability of establishing legumes into existing grass pastures than increasing seeding rate. The price of many of the tropical legumes are typically $20-$30/kg; therefore the higher seeding rates equate to hundreds of dollars expenditure per hectare. The results from the trials described in Section 4 suggest that graziers are far better investing in better seedbed preparation than in higher seeding rates

4 Better agronomy improves legume establishment

4.1 Introduction

Poor establishment of legumes into existing grass pastures is common in the sub-tropics, but industry routinely uses low cost methodologies that are high risk (Peck *et al.*, 2011). In the same environment, farmers use dramatically different agronomic approaches to grow grain crops to alleviate the impacts of seasonal variability. Similarly graziers sowing leucaena now routinely use better agronomy which has taken leucaena from being considered the riskiest pasture legume to establish to being considered the most reliable by industry.

The trials described in this section of the report aimed to investigate the impact of improved agronomic practices on legume establishment for small seeded legumes suitable for the Brigalow Belt bio-region (e.g. desmanthus and Caatinga stylo). In effect the treatments tested the impact of:

- Varying fallow periods through its impact on soil moisture storage, mineralisation of plant nutrients and competition from existing grass and weeds (through killing existing plants and reducing the soil seed bank)
- Seedbed preparation through cultivation or zero tillage
- Different levels of control of competition from grass and weeds post sowing through the use of selective herbicides.
- Different types of tillage (discs, tynes, deep rippers) for one pass cultivation sowing.

4.2 Methodology

These trials investigated the impact of better agronomic practices that are commonly used for grain cropping in the Brigalow Belt bio-region on establishing small seeded pasture legumes into existing grass pastures. Treatments were a combination of fallow period, seedbed preparation (zero tillage or cultivation), post-emergent weed control and sowing method.

Six trials across three districts (Wandoan, Goondiwindi and St George) and two soil types (grey cracking clays and loamy surfaced soils) were conducted over 4 years to test the impact of better agronomy on establishing small seeded legumes into existing grass pastures. This array of districts and soil types was selected in order to capture a broad insight into the effectiveness of the treatments applied across a range of geo-climatic environments within the Queensland portion of the Brigalow belt bioregion. For instance, it was anticipated that loam and clay soil types would vary in their capacity to store moisture during fallows, form soil crusts after rain and have different weed pressures. It was also expected that localities with lower annual average rainfalls would pose more challenges in achieving fallow moisture storage and plant survival.

4.2.1 Trial design and treatments

The trials were designed with 5.5 m wide by 20 m long plots with grass strips (either 4.5 or 2.5 m) left between each plot with two replicates of each treatment. Clay soil trial sites were sown with Progardes desmanthus (a blend of five varieties from three *Desmanthus spp.*). The Wandoan loam soil site was sown with fine-stem stylo (*Stylosanthes guinensis var. intermedia*); Goondiwindi and St George loam sites were sown with Caatinga stylo (*Stylosanthes seabrana cv. Primar* and *Unica*).

A full description of treatments is provided in Table 2. There were 30 treatments in total, with most treatments also having split plots in which seed was either drilled with a single disc opener planter or broadcast. The one-pass cultivation treatments described below did not have split plots, that is seed was broadcast over the whole plot, as graziers would most likely spread seed at the same time as cultivation in a one pass operation as opposed to drilling seed as part of a second operation. Not all treatments were included at each site.

Treatments were a combination of fallow period (i.e. period from first treatment to control the grass until sowing); seedbed preparation (zero tillage or cultivated); and post-emergent weed control as follows:

- No disturbance of the grass pasture.
- Grass pasture disturbed at plant through: slashing; cultivation with a deep ripper, tynes or off-set discs; herbicide spray (glyphosate) with no-post emergence herbicides.
- Short fallows of 2 - 4 months using herbicide (i.e. zero tillage (ZT)), cultivation or both.
- Medium fallow of about 4 - 6 months using either ZT or cultivation.
- Long fallow of about 4 - 6 months using either ZT or cultivation.

Zero-till herbicide applications were conducted primarily using a mix of Roundup® at 2L/ha and LI-700® wetting agent at 250ml/ha. Where broadleaf weeds needed to be controlled 2,4-Dimethylamine (2,4-D) or Starane® (Fluroxypyr) were used. Multiple herbicide applications were used during the fallow period depending on the time period of the particular fallow, rainfall and weed loads.

Cultivated fallows were conducted slightly differently for the different locations as follows:

- Wandoan: The medium fallows were initially cultivated with off-set discs, with subsequent treatments using a chisel plough. Short fallows used a chisel plough only.
- Goondiwindi: All cultivated fallows were initially cultivated with offset discs with longer fallows being treated on two separate occasions. Herbicides were used during the fallow period for the long cultivated fallow treatments once a uniform seed-bed had been created after the second cultivation to try and maintain some ground cover.
- St George: All cultivated fallows were initially worked up using a one way disc plough with the centre of the plots being worked twice due to the width of the grazier's machine. After the initial cultivation treatment, herbicides were used to try and maintain ground cover to maximise soil water storage.

Within the fallow treatments there were also with and without post emergent weed control treatments. The ZT with post-emergent selective herbicide plots were treated as required with either Basagran® at 1L/ha with LI-700® at 200ml/100L for broadleaf weed control and/or Verdict 520® at 100mls/ha with LI-700® at 200ml/100L for control of grass. In the cultivation treatments that received post-emergent herbicide, Spinnaker® was applied at a rate of 50g/ha. Chemical active constituents are summarised for all applied herbicides in Table 1.

Table 1: Active constituents of herbicide chemicals applied in the study.

Chemical Trade Name	Active Constituent
Roundup®	540 g/L glyphosate (present as the potassium salt)
LI-700®	350g/L soyal phospholipids, 350g/L Proprionic acid
Basagran®	480 g/L bentazone (present as sodium salt)
Verdict 520®	520 g/L haloxyfop present as the haloxyfop-R methyl ester
Spinnaker®	700 g/kg imazethapyr

Legume plant numbers and pasture biomass were measured for up to 3 years post sowing. Destructive biomass estimates were taken after a minimum of 12 months after germinating rain. The trial sites were grazed through winter but un-grazed during summer to allow the measurement of plant growth.

Table 2: Description of establishment trial treatments and the districts within which they were applied.

Treatment count	Fallow period	Seedbed treatment	Post plant weed control	Sowing (split plots)	District †
1	No disturbance	None	Nil	Drill and broadcast	W,G,S
2	Disturb at plant	Slash	Nil	Drill and broadcast	W,G,S
3		Deep rip	Nil	Broadcast only	W,G,S
4		Cultivate (tynes)	Nil	Broadcast only	W,G,S
5		Cultivate (discs)	Nil	Broadcast only	G,S
6		Spray	Nil	Drill and broadcast	W,G,S
7	Short (2-4 months)	Zero-till (ZT)	Nil	Drill and broadcast	W,S
8			PEH*	Drill and broadcast	W,S
9		Cultivate	Nil	Drill and broadcast	W,S
10			Spinnaker	Drill and broadcast	W,S
11		Cultivate then spray	Nil	Drill and broadcast	S
12			PEH*	Drill and broadcast	S
13		Spray then cultivate	Nil	Drill and broadcast	W
14	Medium (4-6 months)	Zero-till	Nil	Drill and broadcast	W,G,S
15			PEH*	Drill and broadcast	W,G,S
16		ZT + grass seed	Nil	Drill and broadcast	W
17		Cultivate	Nil	Drill and broadcast	W,G,S
18			Spinnaker	Drill and broadcast	W,G,S
19		Cult. + grass seed	Nil	Drill and broadcast	W
20	Long (9-18 months)	Zero-till	Nil	Drill and broadcast	G,S
21			PEH*	Drill and broadcast	G,S
22			PEH* 2nd summer	Drill and broadcast	G,S
23		Cultivate	Nil	Drill and broadcast	G,S
24			Spinnaker	Drill and broadcast	G,S
25			2 Spinnaker applications	Drill and broadcast	G,S
26		Cult. + grass seed	Nil	Drill and broadcast	G
27	Long + medic	ZT Medic	PEH*	Drill and broadcast	G
28		Cultivate + medic	Spinnaker	Drill and broadcast	G
29		Cultivate + medic + P fert.	Nil	Drill and broadcast	G
30		Cultivate + medic + P fert.	Post emergence herbicide	Drill and broadcast	G

* PEH: post-emergence herbicide; † District: W is Wandoan, G is Goondiwindi, S is St George.

4.2.2 Medic treatments

Due to drought conditions at the Goondiwindi trial site (Table 4) sowing was held over by a year. This delay in planting allowed the inclusion of more long fallow treatments including the addition of planting medic in winter prior to sowing summer growing legumes in the following season. These treatments were fallowed for six months via either zero-till herbicide application or cultivation. The seedbed fallow preparations can be summarised as follows:

- Zero-till with post-emergent selective herbicide.
- Cultivation with Spinnaker® post-emergent herbicide.
- Cultivation with phosphorus applied at 20kg/ha.
- Cultivation with phosphorus applied at 20kg/ha and Spinnaker® post-emergent herbicide.

Each plot was divided in half and each half randomly assigned to be sown either by broadcast or drilling in late April 2014. An equally weighted mix of three medic cultivars (*Medicago truncatula cv. Jester & cv.Caliph and Medicago orbicularis cv. Bindaroo Gold*) was sown at a total seeding rate of 3kg/ha. Drilling was conducted using a single disc opener planter with seeds placed at a shallow depth (<10mm). Broadcasting seed was done by hand. Phosphorus was applied at the time of planting at a rate of 20kg/ha in the form of superphosphate via shallow tines to the relevant plots. Rigid mesh grazing exclosures (2m x 1m) were erected in the centre of each split plot (one in the broadcast end and one in the drilled end). Plots were measured within the grazing exclosures for plant population and total medic dry matter using 1m x 1m quadrats at the end of September 2014.

4.2.3 Sowing dates

All trials were sown in the first two weeks of February of their respective years (Wandoan in 2013 and both St George and Goondiwindi in 2015). All sites received below average rainfall during the fallow periods. Sowing in February was to allow as long a fallow period over spring and summer as possible, while still leaving enough time for seedlings to develop into strong plants and produce some seed prior to the onset of winter. This time of year has better prospects of germinating rain with follow up rain and daytime temperatures tend to be cooler than earlier in summer.

4.3 Results and discussion

4.3.1 Germinating rain and seasonal conditions

Rainfall across all trial sites was below average during the trials. The best annual rainfall recorded across any site in any year was a decile 4 (driest 40% of years). The driest year was a decile 0.5 (driest 5% of years) at the St George site which is also the driest location (i.e. lowest average annual rainfall). The low rainfall reduced the soil moisture storage during the fallow period as well as having low rainfall for the establishing legumes.

The following sections discuss the seasonal conditions recorded for each of the three trial districts (St George, Goondiwindi and Wandoan). Tables are presented to summarise dates for fallow commencement and sowing, along with significant recorded rainfall data for each of the sites, relative to historical records.

4.3.1.1 St George Site Rainfall

The St George establishment trial sites were prepared, fallowed, planted and maintained through a sustained succession of drought years. The St George trial sites also have the lowest average annual rainfall (AAR) of the three districts. Well below average rainfall over the course of the experimental period gave rise to an almost complete establishment failure 12 months after sowing. Only the long fallow treatments retained plants at 14 months after germinating rains (Fig. 23 and Fig. 35).

Long fallows were commenced in March 2014. On-site rainfall for both of the sites was within the 5th percentile (0.5 decile), relative to historical records (driest 5% of years), with the loam site recording a lower total than has ever been recorded at the nearest Bureau of Meteorology station (Nindigully) (Table 3).

At both the clay and loam sites, 34 mm was received for December and 62 mm for January and the sites were planted on the 6th of February 2015. Germinating rains arrived three weeks later on the 1st of March (20mm), with a further 16 mm arriving on the 11th of February and 55 mm and 65 mm on the loam and clay sites respectively on the 4th of April. No notable other falls were recorded until the 16th of June when 64 mm were recorded, by which time the legumes growth was retarded by winter.

Calendar year rainfall totals for 2015 were again very poor, with the loam and clay soil sites registering decile 2 and decile 3 years respectively. The detrimental effects of these very poor rainfall totals on legume survival, growth and persistence were further compounded by the timing and distribution of the falls across the season, with 40% falling during the winter months when the summer growing legumes that were sown were dormant and any available moisture was exhausted by annual medics, herbage and weeds (Fig. 8). In contrast to the Goondiwindi site conditions in 2015, the St George site was not the beneficiary of any spring rainfall. This meant that plants that had survived winter, received no spring rain reprieve and entered the summer and heatwave conditions with a dry soil profile.

In the period from 1 September 2015 to April 30 2015 a total of 107 mm and 132 mm fell across the loam and clay sites respectively. These totals consisted of a series of small falls, with only one exceeding 20 mm (36 mm January 3). The next notable rainfall events were not recorded until the 2nd of May (20 mm), followed by two falls of 37 mm and 30 mm in June. These poor conditions lead to very poor plant survival rates at both sites to14 months from first germinating rains.

Table 3: St George site rainfall data summary for duration of fallows and experimental period.

Site:	Loam	Clay
Average annual rain (Nindigully)	517.3	
Median annual rain (Nindigully)	484.35	
Long fallows commenced	5/03/2014	
Sowing date	6/02/2015	
Fallow Year Rainfall (2014)		
Rainfall for fallow calendar year (BOM)	352.00	
Rainfall for fallow calendar year (trial records)	186	216
Decile year of fallow (BOM)	1	
Decile rating year of fallow (trial records)	0.5	0.5
Germinating Rain Events		
1st germinating rain date	1/03/2015	
1st Germinating rain amount	20	
2nd germinating rain event	11/02/2016	
2nd germinating rain amount	16.00	19
3rd germinating rain event	4/04/2015	
3rd germinating rain amount	55.00	65
Year 1 Rainfall (2015)		
Rain total for calendar year of sowing (BOM)	364.1	
Rainfall for calendar year of sowing (trial records)	344	392
Decile (BOM records)	3	
Decile (trial records)	2	3

Fig. 8: Winter medic, weed and herbage growth at the St George loam soil establishment site in 2015. Rainfall for the year was well below average (decile 2), with the majority of rain falling in autumn and winter, at a time when the summer growing legumes were dormant and available moisture was utilised by winter growing annual medics, weeds and herbage.

4.3.1.2 Goondiwindi site rainfall

Fallowing was initiated in late August 2013 at the Goondiwindi trial sites. The proceeding autumn and summer periods failed to deliver adequate rainfall to permit a February-March 2014 plant, as initially planned. The calendar year total for 2013 year of fallow only amounted to a decile 2 year.

Following continued dry conditions towards the end of the 2013/14 summer, the decision was made to delay planting until the following summer and continue fallow operations through winter in an attempt to store further moisture. This decision was also made to accommodate the inclusion of several new longer fallow treatments that had not been applied at the Wandoan site in 2013. Results from this trial site had indicated that the medium length fallow periods applied may not have been adequate for the storage of sufficient fallow moisture.

Rainfall for the remainder of 2014 proved to be well below average, with the total for the year only tallying 346mm (decile 2) (Table 4).

The sites were planted on the 2nd of February 2015 and the first germinating rains arrived within two weeks on the 20th of February (30.5 mm) which gave rise to the first wave of seedlings. This was followed by a period of hot dry weather that killed many seedlings, particularly within the treatments that had not stored soil moisture. A second significant rainfall event followed, six weeks after the first on the 4th of April (61 mm), triggering a second germination event. These two rainfall events gave rise to two broad cohorts of legume seedlings going into winter. Seedlings in medium and long fallows that had emerged at the first germination accessed stored soil moisture and survived the dry weather until the second rainfall event resulting in two seedling sizes. By contrast, there were very high death rates of seedlings before the second rainfall event in treatments without stored soil moisture (i.e. no disturbance and disturb at plant treatments).

For the remainder of the year, for loam and clay sites respectively, notable rainfall events included 60 and 21 mm in mid-July, 55 and 70 mm in mid-September and 92 and 77 mm at the end of November, giving rise to a year total of 385.5 mm (decile 2). For plants that survived the first winter, the timing of this spring rainfall was likely to have been critical to their survival into summer, which proved to be very dry with no further rain events recorded until early May 2016 (37 and 43mm).

Table 4: Goondiwindi site rainfall data summary for duration of fallows and experimental period

Average annual rainfall	551.95
Median rainfall (Toobeah Post Office)	546.65
Long fallows commenced	21/08/2013
Sowing date	2/02/2015
Fallow Year Rainfall (2014)	
Rainfall for fallow calendar year (BOM records)	284.70
Rainfall for fallow calendar year (trial records)	346.5
Decile (BOM records)	1
Decile (trial records)	2
Germinating Rain Events	
1st germinating rain date	20/02/2015
Germinating rain amount	30.5
2nd germinating rain event	4/04/2015
2nd germinating rain amount	61.00
Year 1 Rainfall (2015)	
Rain total for calendar year of sowing (BOM records)	364.1
Rainfall for calendar year of sowing (our	385.5
Decile (BOM records)	2
Decile (trial records)	2

4.3.1.3 Wandoan site rainfall

Fallowing commenced at the Wandoan trial sites on the 12th of September 2012. These trials did not have long fallow treatments (>9 month fallows). Rainfall for the overall fallow year (2012) was poor (decile 2)(Table 5) and only limited amounts of soil moisture were stored during the medium length fallows which are the longest fallow period at these trial sites.

Both the clay and loam sites were sown over the 13th to the 14th of February 2013. Germinating rains were recorded in the proceeding days (15th – 18th of February), amounting to 45 mm (Table 5). This total, accrued over a succession of days provided ideal conditions for germination and resulted in the emergence of the bulk of sown seed in a single cohort. A further 89 mm was recorded on the 1st to the 2nd of March. These substantial early falls, arriving in quick succession produced good early growth and survival of legume plants, particularly within plots that had stored some moisture through fallowing. These favourable rainfall conditions were able to compensate for the relatively poor rainfall received during the fallow period, improving seedling survival and subsequent plant growth and seed production in the lead up to the first winter.

Rainfall in subsequent years at this locality was well below average with 2013, 2014 and 2015 recording decile 1, 3 and 4 rainfall totals respectively.

Table 5: Wandoan site rainfall data summary for duration of fallows and experimental period

Average annual rainfall (Wandoan Post Office)	629.6
Median rainfall (Wandoan Post Office)	606.2
Medium fallows commenced	12/09/2012
Sowing date	13/02/2013
Fallow Year Rainfall (2012)	
Rainfall for fallow calendar year (BOM records)	507.2
Decile year of fallow (BOM records)	2
Germinating Rain Events	
Germinating rain dates	15-18/02/2013
Germinating rain amount	45
Follow up rainfall event*	01-02/03/2013
Follow up rainfall event amount	89
Year 1 Rainfall (2013)	
Rain total for calendar year of sowing	381.4
Decile year of sowing	1
Year 2 Rainfall (2014)	
Year 2 rainfall	540.2
Year 2 rainfall decile	3
Year 3 Rainfall (2015)	
Year 3 rainfall	560.2
Year 3 rainfall decile	4

4.3.2 General observations across sites

4.3.2.1 General observations across clay and loam soil types

Across the two broad soil types within the overall experiment, there were some commonalities observed in weed loads, emergence and response to sowing method.

A general observation was that the loam soil trials tended to have a higher weed load than the clay soils. This may have been associated with the higher plant available water capacity of the loam soils, meaning that the small and intermittent showers received throughout the period of the trial were more likely to give rise to germination of weed seeds. The loam soils had less competitive grass pastures at the Wandoan and Goondiwindi trials which would provide less competition to weeds.

There tended to be a higher plant densities in response to germinating rains on the loam sites compared with the clay sites. Again, this is likely to have been associated with the higher water availability of the loam soils, in combination with the relatively small germinating showers recorded across all sites for the duration of the experimental period. On loam soils, a greater degree of moisture from each rainfall event would have been available for germination and plant growth.

4.3.3 Impact of fallows on existing grass, grass and weed seed banks and soil moisture storage

The treatments applied across each of the experimental sites was intended to investigate a spectrum of grass disturbance and fallow periods and their effects on legume survival and growth. Primarily, these treatments influenced the conditions for legume growth and survival through the degree to which they removed existing grass competition, reduced weed and grass seedling competition through partially exhausting the soil seed bank and through the storage of fallow soil moisture. A broad summary of these treatment effects is contained in Table 6.

4.3.3.1 No disturbance treatments

The no disturbance of the existing pasture treatment did nothing to improve the conditions for emerging seedlings. This treatment is common practice within industry but it does nothing to reduce existing grass competition or reduce weed and grass seed banks; nor does it store any soil moisture for emerging seedlings. It is interesting to note that this treatment, had both broadcast and drill sowing methods applied to it. Drilling of seed would be considered by many within industry to constitute a high level of input and preparation despite there being poor legume establishment within the no disturbance treatment at all trials within this study.

4.3.3.2 Disturb at plant treatments

In general, the low input treatments involving disturbance of the existing pasture only at sowing did little to improve the conditions for emerging seedlings. These treatments did little to reduce existing grass competition or seed banks in the soil and did not store moisture for emerging seedlings.

The disturb at plant treatments (cultivate, spray and slash) had varying effects on the removal of existing grass tussocks, but did not store any moisture for emerging seedlings to access. The use of cultivation at planting tended to achieve only limited to moderate levels of grass kill and this was dependant on both the implement used and the follow up rain received. If rain was received soon after cultivation, the tilled grass tussocks were less likely to die and the plants could re-establish root systems and recover. Discs achieved a high level of disturbance of grass. A high level of disturbance was achieved with the use of tynes in the form of a chisel plough at the Goondiwindi and St George sites, whereas at Wandoan the use of spear points resulted in less grass disturbance. Deep rippers were on 1 m spacing's which resulted in fewer plants being disturbed but a deeper disturbance to the soil.

Spraying at plant did achieve a higher grass kill than cultivation but its effectiveness was dependent on the presence of green leaf on the plants to facilitate uptake and translocation of the herbicide. Spraying at planting permitted no moisture storage.

Using either cultivation or spraying single pass treatments can open up bare soil within the pasture and have reduced competition from the grasses for a period which can allow broadleaf weeds to establish.

Slashing did not kill any plants or store any moisture for emerging seedlings. This treatment was observed as producing stunted grass growth and recovery up to 12 months following application (Fig. 9). Measured biomass recovery over time from these treatments was lower than other treatments that resulted in greater disturbance of the existing pasture but the results were not significant.

Fig. 9: Example of the depressed buffel grass growth 10 months following slashing at the Goondiwindi clay soil establishment site.

4.3.3.3 Short fallow treatments (2-4 months)

The short fallow treatments (2-4 months) resulted in a high degree of kill (approximately 80%) of existing grass tussocks was achieved with cultivation treatments. Herbicide was limited in its effectiveness due to the dry seasonal conditions recorded across all sites prior to sowing which resulted in poor grass growth and therefore limited spraying opportunities during the fallow period.

The timing of fallow commencement in spring when conditions are often dry, in combination with the poor seasonal conditions during the fallow period also meant that only limited amounts of moisture were stored in the subsoil for these short fallow treatments. Grass and weed seedbanks were likely to have only been lightly affected during these short fallow periods, particularly as there were so few germinating rain events in which to exhaust soil seed levels. Due to this lack of weed seedbank exhaustion, broadleaf weeds and grasses were able to recolonise bare ground and gaps in the pasture. Cultivation may have reduced the weed and grass seed burden more than spraying through the burial of seed .

4.3.3.4 Medium fallow treatments (4-6 months)

Medium fallows (4-6 months) achieved a high kill (approximately 90%) rate of existing grass tussocks through the application of cultivation. A comparatively poor kill was achieved through herbicide application. This was due to the timing of commencement of the medium fallow periods aligning with the end of winter and early spring, when the grass is usually dormant and conditions are often dry. This in effect, delayed the application of the first spray, and in combination with the poor seasonal conditions and lack of grass growth, lead to a low rate of grass kill and only a moderate amount of fallow moisture storage.

Broadleaf weeds burden were only moderately affected with the limited spray and cultivation opportunities. Grass and weed seedbanks were likely to have only been moderately impacted during these medium fallow periods, particularly as there were relatively few germinating rain events in which to exhaust soil seed reserves. As within the short fallows, the cultivation is likely to have reduced the weed and grass seed burden somewhat more than spraying through the burial of seed.

4.3.3.5 Long fallow treatments (9-12 months)

Long fallow treatments achieved approximately 100% kill of existing grass tussocks with the application of either cultivation or spray (Fig. 10). The majority of broadleaf weeds were eliminated and the weed and grass seedbanks were significantly reduced through the course of multiple germinations and follow-up treatments. Over the course of the fallow period, these treatments were able to build up relatively higher levels of soil moisture than other treatments, despite the seasonal conditions having been well below average.

Fig. 10: Example of desmanthus seedling emergence within a drilled sowing zero tillage fallow treatment at the Goondiwindi clay soil establishment site.

Table 6: Generalised conceptual model of the impact of fallow periods and seedbed preparation methods on pasture seedbank and soil water.

Level of disturbance or length of fallow:	**No disturbance**	**Disturb at plant** (cultivate*, spray, slash)	**Short fallow (2-4 months)** (cultivate, spray)	**Medium fallow (4-6 months)** (cultivate, spray)	**Long fallow (9-12 months)** (cultivate, spray)
Effects on existing grass tussocks:	None	• Limited to moderate grass kill with cultivation (depending on implement used and follow up rain). • Higher grass kill with herbicide (depending on green leaf area at plant) • Stunting of tussocks and slower recovery with slashing	• High kill rate (80%) of existing grass tussocks with cultivation • Limited kill of existing grass tussocks with herbicide due to dry seasons and limited grass growth during the fallow period.	• High kill rate (90%) with cultivation of existing grass tussocks • Poorer kill from spray due to lack of green leaf as a result of little rain during spring and early summer	• 100% kill of existing grass tussocks with spray or cultivation, some recolonization from seed.
Effects on broadleaf weeds	None, very few weeds due to grass competition	None, very few weeds due to grass competition	Limited	Moderate	Moderate to high
Effects on grass & weed seed bank	None	None	Limited	Moderate (seedbank partially exhausted)	High impact (seedbank significantly reduced)
Effects on soil water storage at planting	No stored moisture	No stored moisture	Limited (due to dry spring and early summer)	Moderate	High

*Cultivation treatments at plant were deep ripping, tynes or discs. Discs were an effective form of grass removal and kill. The tyne machine was a chisel plough at Goondiwindi and St George, which achieved a high level of disturbance; at Wandoan spear points were used which resulted in less disturbance. Deep rippers were on 1 m spacing which resulted in fewer plants being disturbed but a deeper disturbance to the soil.

4.3.4 Emergence and early growth (1 – 3 months growth)

4.3.4.1 Legume density and height

At all sites, fallowing resulted in more legume plants that were larger. All treatments had the same seeding rate sown at the same time, therefore higher plant numbers and size in fallowed treatments can be attributed to better germination and emergence, better survival and higher growth rates or a combination of all of these factors.

The St George loam soil trial site is used as the main example for this discussion as the St George sites were the only trials that included short (2-4 months), medium (4-6 months) and long fallows (9-12 months). The Wandoan trials did not include long fallows and the Goondiwindi trials did not include short fallows. Goondiwindi loam is used as an example for demonstrating death of seedlings during early growth for treatments that did not store soil moisture prior to sowing. Legume density at the St George loam soil site for six and nine weeks is shown in Fig. 17, legume density for the other trial sites are shown in Appendix 1.

Legume density at the St George loam soil trial site shows a clear trend of increased legume (Caatinga stylo) density with increased fallow length at 6 and 9 weeks after germinating rain (Fig. 17). Similarly there is a clear trend of increasing plant height with increasing fallow period at these recording periods (Fig. 18). The tiny plants in the no disturbance and disturb at plant treatments only grew from approximately 10mm to 20mm between recordings at week 6 and 9. By contrast the fallowed treatments grew better, increasing in height by 25-60 mm between the two recordings and were much larger in size at 9 weeks (approximately 55-115mm).

The results at the St George loam soil trial sites are consistent with the other trial sites (Appendix 1). That is, at all sites increasing fallow periods resulted in increased legume density and bigger plants in the first few months of establishment. Within this overall trend, the different seasonal and soil conditions at the different locations did produce some slightly different results. For example death rates between the recordings of legumes was greater at Goondiwindi.

At Goondiwindi, the impact of competition from existing grass was even more severe than at the St George sites with all of the seedlings in the no disturbance or disturb at plant treatments dying between the first and second measurement (Fig. 11 - Fig. 16). Follow up rainfall resulted in a large increase in legume density between the first and second measurement (Fig. 21). However, the legume height demonstrates that in the no disturbance or disturb at plant treatments it was all newly emerged seedlings with no increase in height between four and eight weeks after germinating rain and a height of <20mm at the second recording (Fig. 19). By contrast, the fallow treatments had grown by approximately 25-120mm to be 60-170mm tall over the same time period (Fig. 19).

Fig. 11: Desmanthus seedling at 4 weeks after germinating rains in a single pass cultivation treatment at the Goondiwindi clay soil establishment site. Most seedling seedlings in this treatment died before additional rainfall was recorded.

Fig. 12: Desmanthus seedling at 4 weeks after germinating rains in a medium fallow sprayed treatment at the Goondiwindi clay soil establishment site. Plants with access to stored fallow moisture grew more rapidly than those without stored moisture.

Fig. 13: Desmanthus seedling at 4 weeks after germinating rains in a long cultivated fallow treatment at the Goondiwindi clay soil establishment site. Plants with access to stored fallow moisture grew more rapidly than those without stored moisture.

Fig. 14: Caatinga stylo seedling at 4 weeks after germinating rains in a single pass cultivation treatment at the Goondiwindi loam soil establishment site. Most seedlings in this treatment died before additional rainfall was recorded.

Fig. 15: Caatinga stylo seedling at 4 weeks after germinating rains in a medium fallow sprayed treatment at the Goondiwindi loam soil establishment site. Plants with access to stored fallow moisture grew more rapidly than those without stored moisture.

Fig. 16: Caatinga stylo seedlings at 8 weeks after germinating rains in a long cultivated fallow treatment at the Goondiwindi loam soil establishment site. Plants with access to stored fallow moisture grew more rapidly and retained greater numbers than those without stored moisture.

Within the same fallow period, there was little difference between cultivated or zero tillage (ZT) seed-bed preparation for plant number or height. There was a trend towards better legume growth with ZT (plant density and size), however there were not statistically significant differences.

By contrast to fallows producing good legume numbers, the most common commercially used and recommended legume establishment treatments of sowing into undisturbed grass or one pass cultivations all failed to produce adequate legume density at all sites.

4.3.4.2 Post emergence herbicide

The post emergence herbicides used in these trials are not registered for desmanthus and Caatinga stylo, however previous trial work suggests they are useful for these legumes (Cox and Harrington, 2005). The herbicides resulted in some negative impacts on early growth of the legumes at some sites, but also had positive impacts at other sites (presumably from reduced weed competition). Examples of the mixed results are:

- At the Goondiwindi clay trial site, visual damage from Spinnaker was observed on desmanthus. Despite the visual damage there was no reduction in plant numbers or height.
- Goondiwindi loam trial showed no difference in plant numbers from the use of herbicides.
- At St George clay trial:
    - Spinnaker reduced desmanthus density in the long fallows. There was also a reduction in the plant numbers in the medium length fallows but not significant ($P<0.05$).
    - Post emergence herbicides (PEH) (Verdict and Basagran) showed a trend towards some suppression of plant numbers in the long and medium fallows but it was not a significant reduction ($P<0.05$).
- St George loam site showed a trend towards improved plant numbers with Spinnaker or PEH, but it was not significant ($P<0.05$).
- Both Wandoan sites showed no difference in plant number or height with herbicide treatments.

These results suggest that under some circumstances, the herbicides can cause some damage to the legume seedlings. The trade-off is whether the damage from weed and grass competition is greater and therefore minor damage from the herbicide in the short term gives greater growth in the subsequent season. Results from the Goondiwindi trials suggest this is the case (Section 4.3.6).

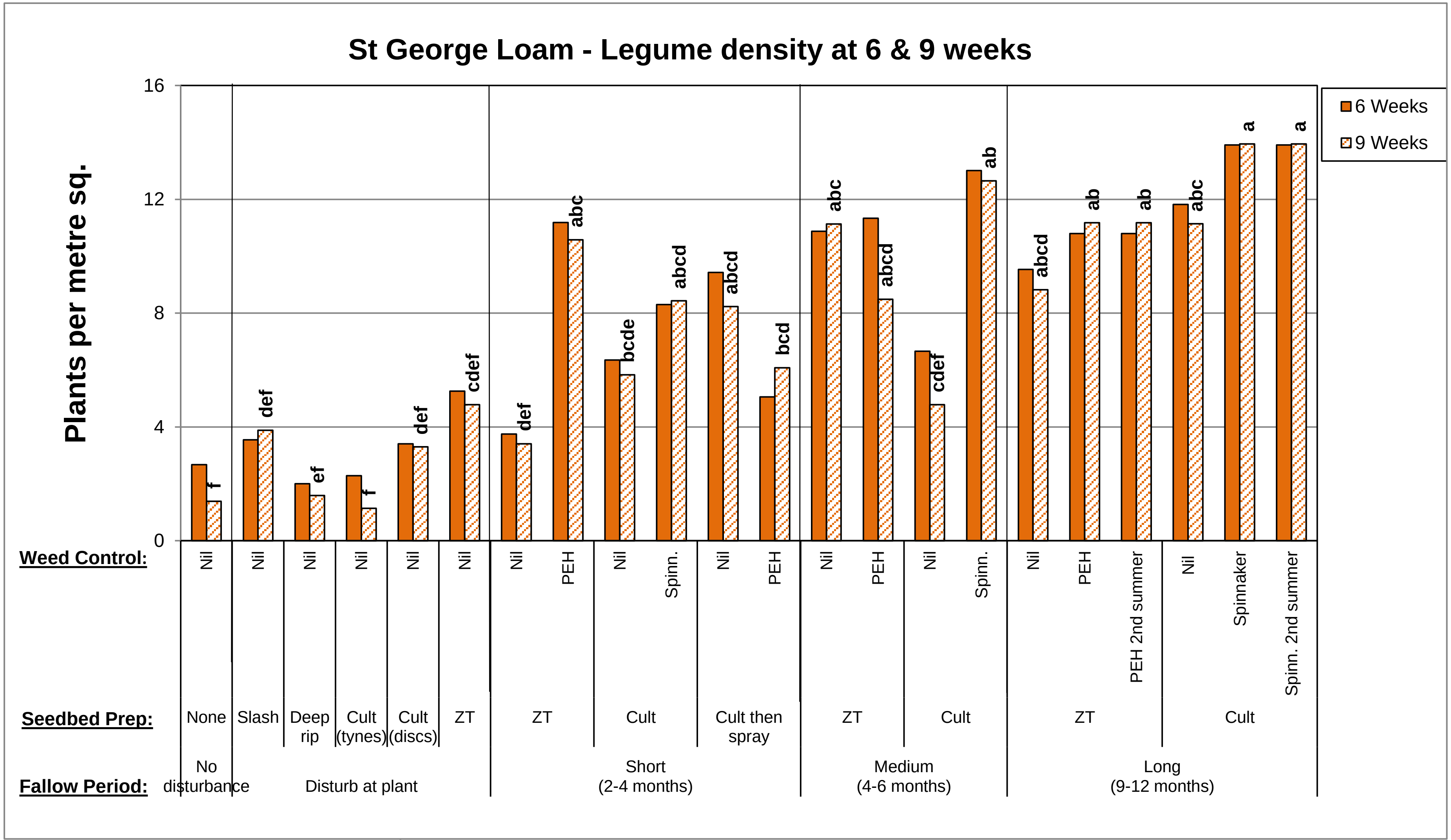

Fig. 17: Legume plant density (plants/m^2) at the St George loam soil legume establishment site 6 and 9 weeks after germinating rain. Statistical differences presented for 9 week data. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

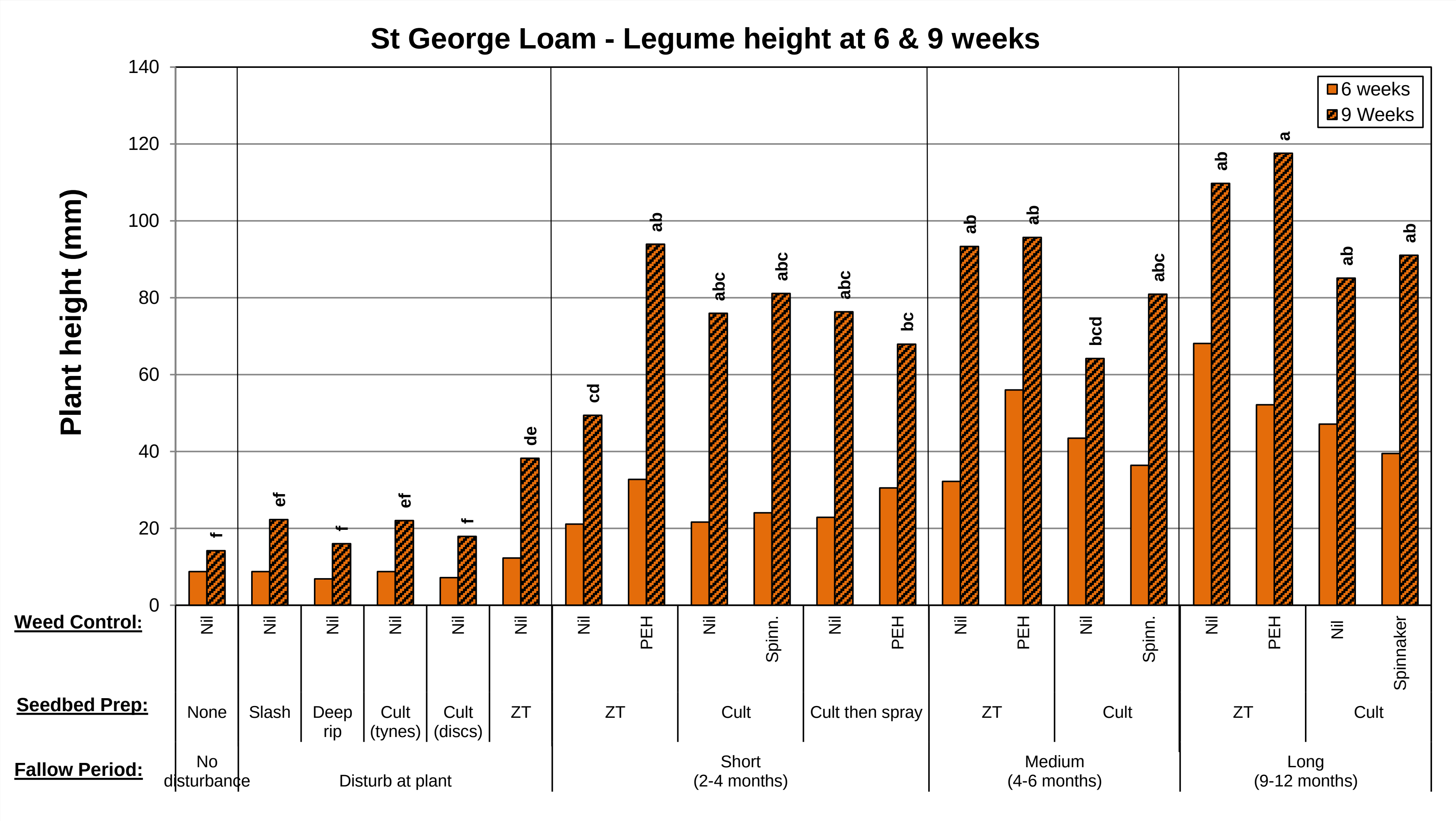

Fig. 18: Legume plant height (mm) at the St George loam soil legume establishment site, 6 and 9 weeks after germinating rains. Significant differences are presented for the 9 week data. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

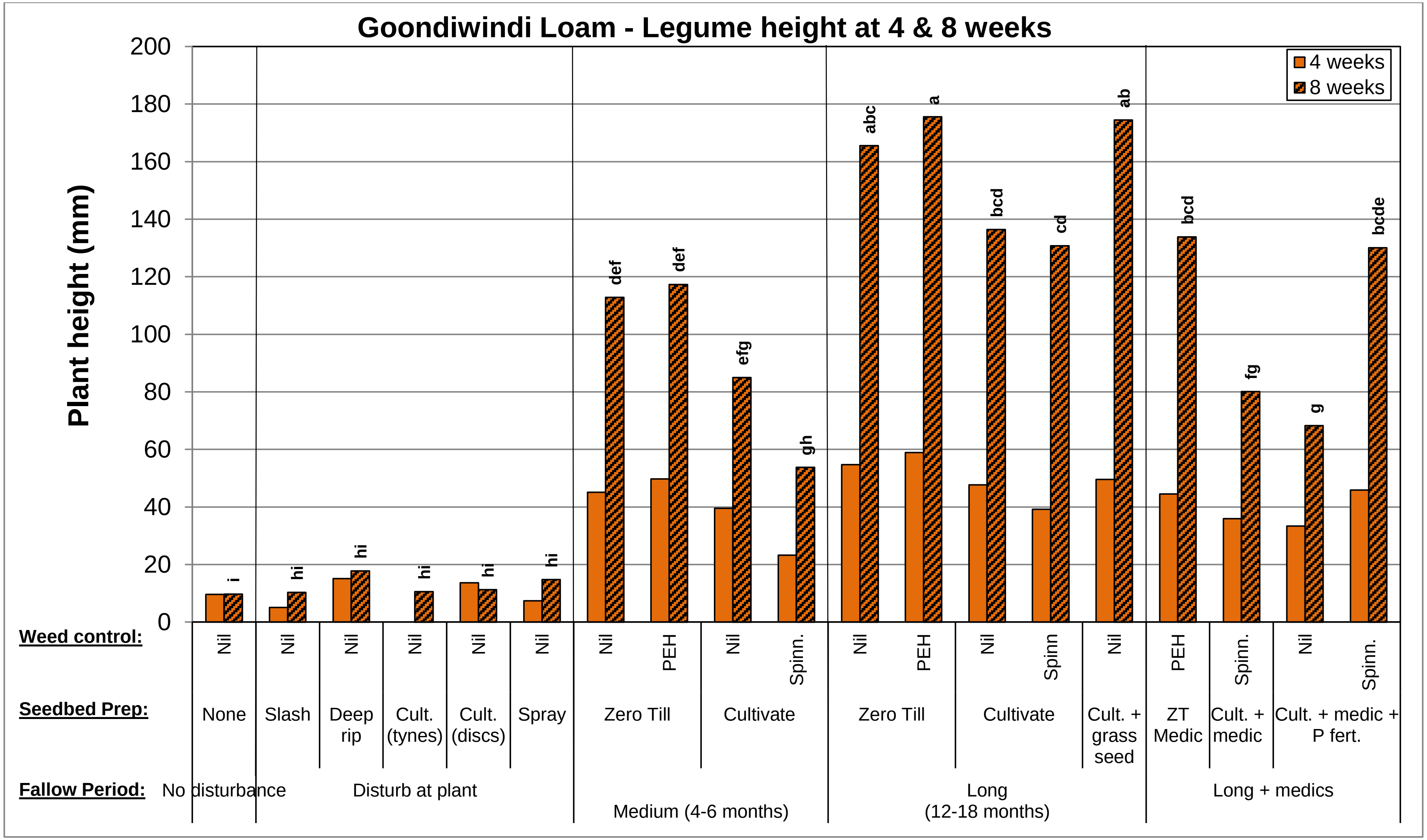

Fig. 19: Legume plant height at the Goondiwindi loam soil legume establishment site, 4 and 8 weeks after germinating rains. Significant differences are presented for the 8 week data (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

4.3.4.3 Effectiveness of drilling seed compared to broadcasting

All treatments except the cultivate at plant treatments had split plots to compare the impact of drilling seed using a single disc opener planter compared to broadcasting seed on the surface of the soil. Drilling has been demonstrated to be beneficial compared to surface broadcasting for most crops and pastures due to improved soil to seed contact, however drilling is difficult for small seeded legumes as seed needs to be placed at approximately 1cm depth or less.

Drilling resulted in more legume plants than broadcasting for at least some treatments at all loam soil sites and the Goondiwindi clay site, but did not increase legume density at the St George or Wandoan clay soil trials (Appendix 1). At the trials that did gain a benefit from drilling, the improvement in plant number was greater in zero tillage plots than in cultivated fallows. At some sites, drilling resulted in reduced legume density in cultivated fallow treatments most likely due to the seed being sown too deep. Goondiwindi loam trial site is an example of these results where drilling improved legume density in zero tillage and treatments that had medic sown in the previous winter treatments, but resulted in lower legume density in cultivated treatments (Fig. 20).

The lack of improvement in plant numbers as a result of drilling at the St George and Wandoan clay soil trial sites suggest that soil and pasture properties at these sites allowed adequate seed to soil contact to facilitate good germination with both methods of sowing.

The results across all six trial sites suggest that drilling is beneficial where it will improve soil to seed contact to facilitate rapid germination. This is most likely to occur with:

- Soil types where the soil surface is firm, that is crusting, hard setting or firm soil surfaces.
- Zero tillage compared to cultivated fallows or planting operations.
- Prior management that has allowed the soil surface to become firm (e.g. the medic treatments at Goondiwindi).
- Pastures with very dense grass cover which reduces broadcast seeds chance of contacting the soil surface.

Drilling is less likely to produce a benefit to legume establishment when:

- The soil surface is self-mulching.
- The pasture has gaps that allow seed to contact the soil surface.

Drilling can improve germination through improving seed to soil contact of small seeded legumes in certain situations, however it should not be attempted unless planting equipment allows very good control of sowing depth. Sowing too deep can result in establishment failure with few or no seedlings able to emerge.

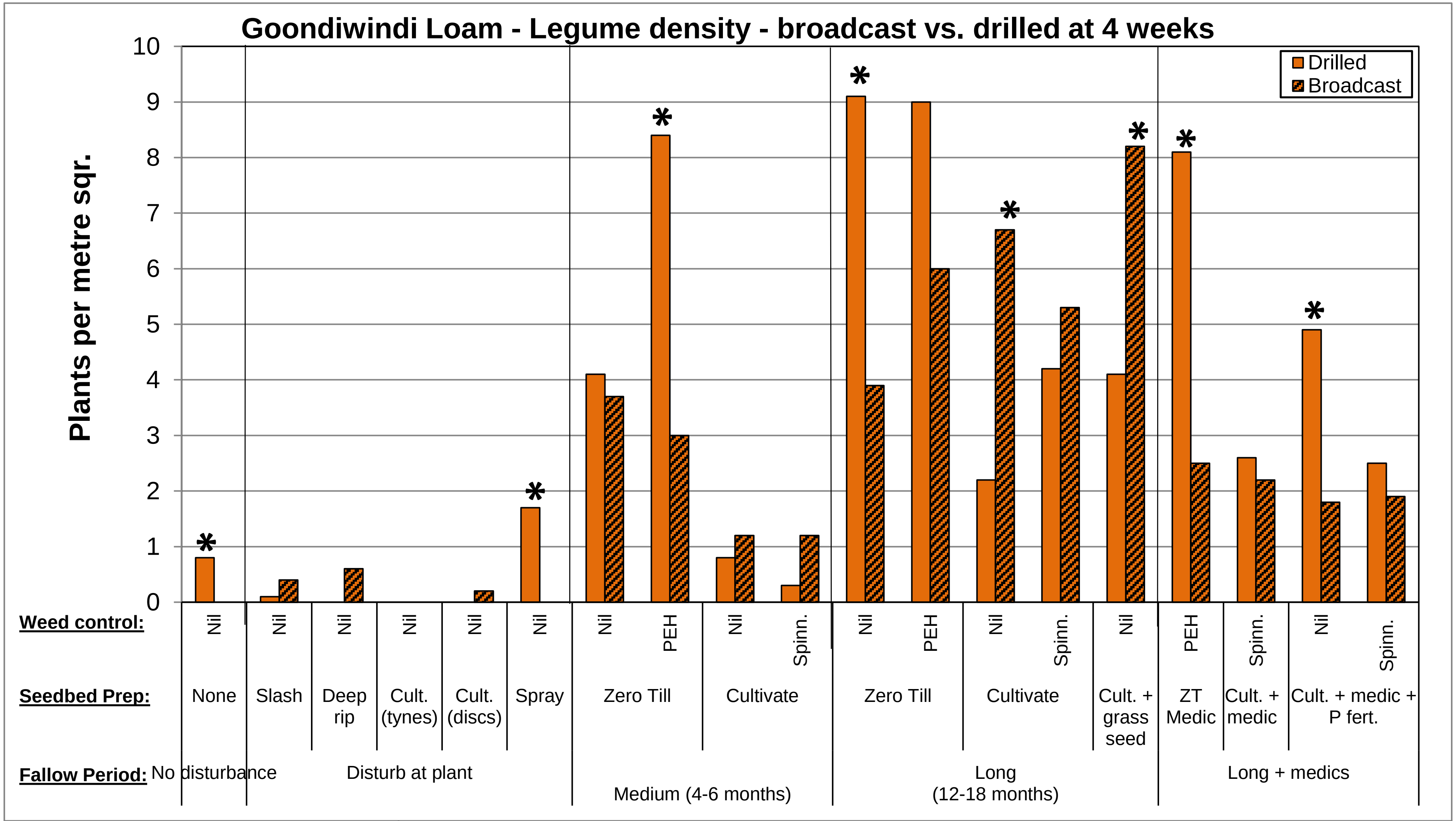

Fig. 20: Legume plant density (plants/m^2) at the Goondiwindi loam soil legume establishment site for drill and broadcast sowing methods, 4 weeks after germinating rain. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

4.3.5 Plant survival to 12 months

All treatments across all sites showed high death rates through the first winter and subsequent growing season. All sites had drier than average seasons (Section 4.3.1). St George had a very dry season following the trials first winter. Fallows sustained higher legume densities at all sites, however both St George trials had very low legume density in all treatments at 12 months (Fig. 23).

The Wandoan loam trial site experienced severe grazing by wildlife (bettongs) and a dry spring. The impact on the fine-stem stylo was so severe that the trial site was not measured beyond the first winter.

4.3.5.1 Legume density

The Goondiwindi (clay and loam) and Wandoan clay sites produced the most meaningful results due to the impacts of drought at St George and grazing at the Wandoan loam trial described above. Fallows sustained higher legume density in all three of these trial sites with Goondiwindi loam being a good example of the results (Fig. 21).

Cultivated fallows with Spinnaker produced the highest legume density at Goondiwindi loam; by contrast ZT produced the highest density at the clay soil trial (Fig. 36). Using Spinnaker resulted in significantly higher legume density at the Goondiwindi loam site for both long and medium fallows; post-emergence herbicides on the zero tillage treatments showed a non-significant trend towards higher plant numbers. In contrast, at the clay site there was no benefit in legume number from using Spinnaker or PEH (on the ZT treatments). This difference between soil types most likely reflects a higher level of weed competition at the loam site. Despite there being no difference in legume density from using Spinnaker at the clay site at 14 months, there was an improvement in legume dry matter production (Fig. 24).

4.3.5.2 Effectiveness of drilling compared to broadcasting

The impact of drilling seed into the soil compared to broadcasting on the surface have endured through to nine months at the Goondiwindi trial sites. At the clay soil site there is an enduring positive effect of drilling in the firmer ZT treatments as well as a negative impact from seed being drilled too deep in the cultivated treatments (Fig. 22).

At the Goondiwindi loam soil site, the benefits of drilling in the firmer surfaced ZT treatments have not endured through to being higher plant numbers at nine months, presumably the impact has been over-ridden by the impacts of competition from other plants and dry weather (Fig. 23). The negative impacts of drilling too deep in the long cultivated fallow treatments have endured.

There was an interesting interaction in the medic treatments at the loam site which initially showed a significant improvement in legume density from drilling in two treatments; but at nine months after germinating rain there is significantly more plants in the broadcast treatment for two of the treatments. This change in legume density may be due to the competitive effects of the medic. The drilled medic produced significantly more plants and dry matter production in its first year (Section 4.3.9), which presumably would have resulted in much higher medic competition in the subsequent winter (i.e. between the 8 weeks and 9 months recordings).

4.3.5.3 Impact of severe drought

St George is the driest location for the trial sites and is at the bottom limit of average annual rainfall where summer growing legumes are recommended. The trials at this locality experienced drought conditions with the fallow calendar year recording an annual total within the 5^{th} percentile, relative to historical records (driest 5% of years). Dry conditions have persisted for the remainder of the trial period, with calendar year totals for 2015 registering deciles of 2 and 3 respectively for the clay and loam sites. The effects of these low totals have been exacerbated by the timing and distribution of the falls across the season, with 40% falling during the winter months when the summer growing legumes that were sown were dormant and any available moisture was quickly exhausted by annual medics, herbage and weeds (Fig. 8).

In contrast to the Goondiwindi site, the St George site was not the beneficiary of any spring rainfall in 2015. This meant that plants that had survived winter, received no spring rain reprieve and entered the spring and summer with a dry soil profile and suffered heatwave conditions. These drought conditions over the experimental period resulted in all treatments failing to support adequate legume densities at St George. The long fallow treatments generally retained some plants at 14 months after germinating rains (Appendix 1). While these treatments still have severely low legume densities, they do demonstrate that fallowing can be useful in mitigating against the risks of seasonal variability, permitting at least a low level of plant survival.

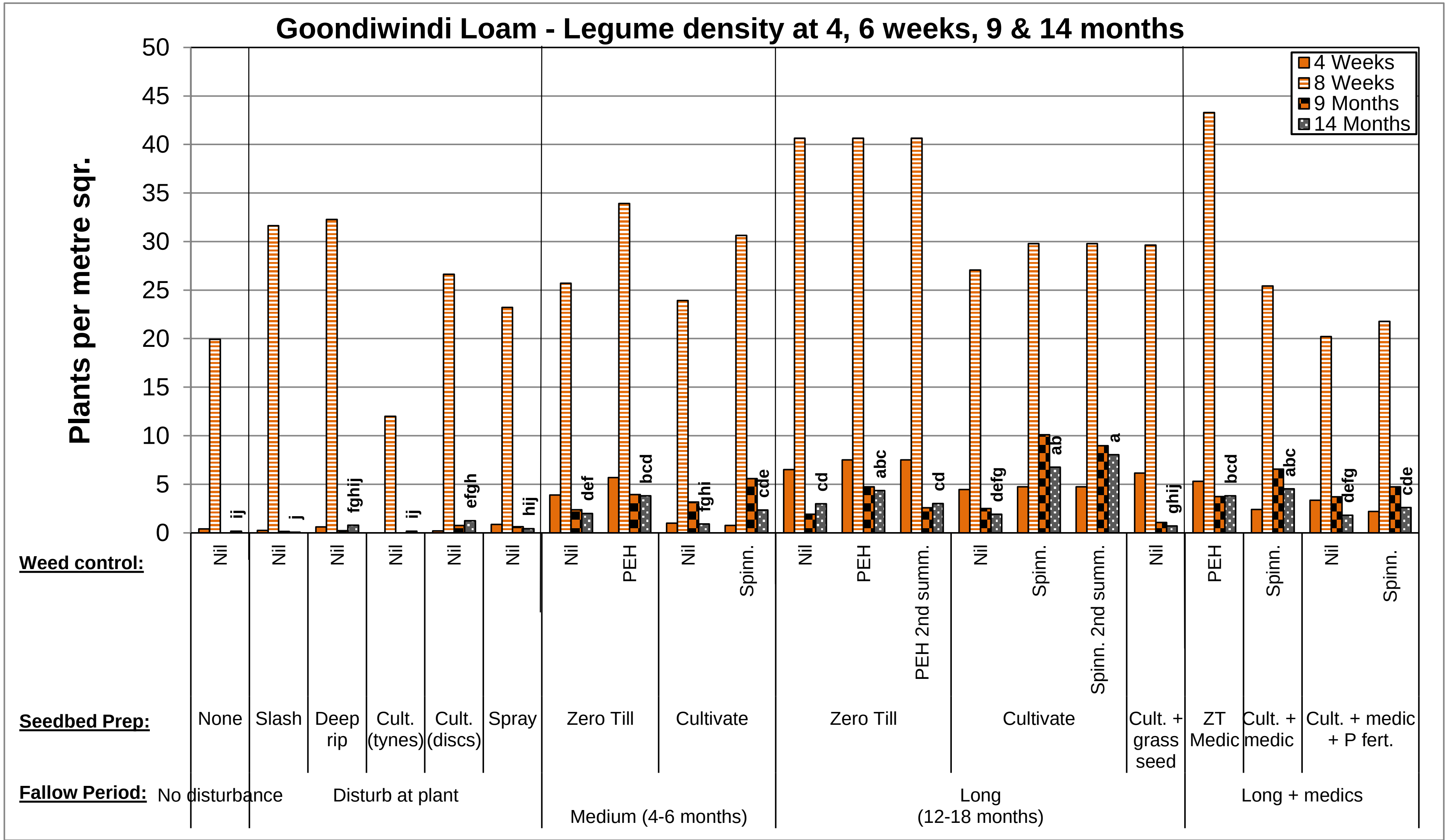

Fig. 21: Legume plant density (plants/m²) at the Goondiwindi loam soil legume establishment site 4 & 8 weeks, 9 & 14 months after germinating rain. Significance is presented for 14 month data (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

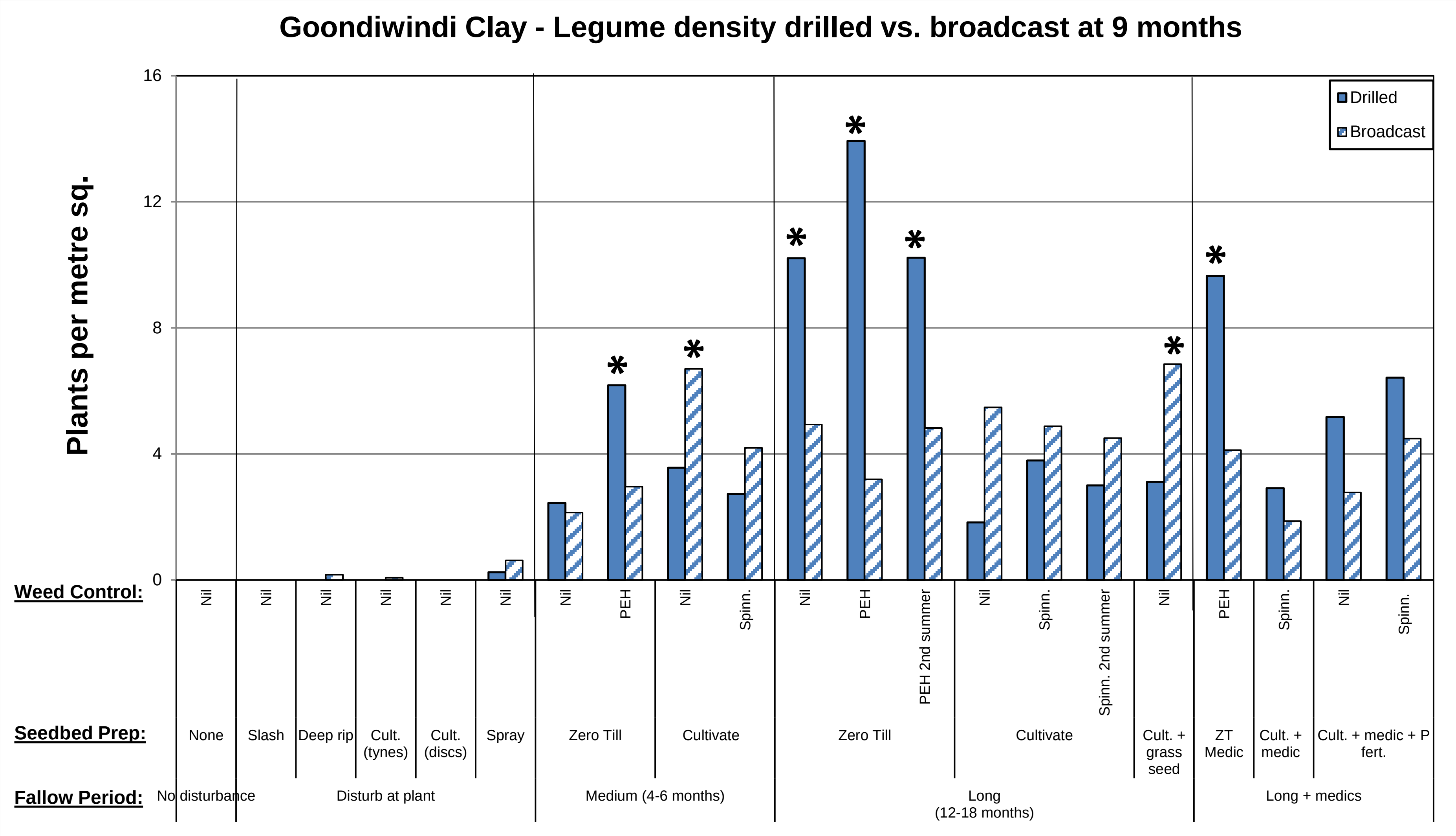

Fig. 22: Legume plant density (plants/m^2) at the Goondiwindi clay soil legume establishment site for drill and broadcast sowing methods, 9 months after germinating rain. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

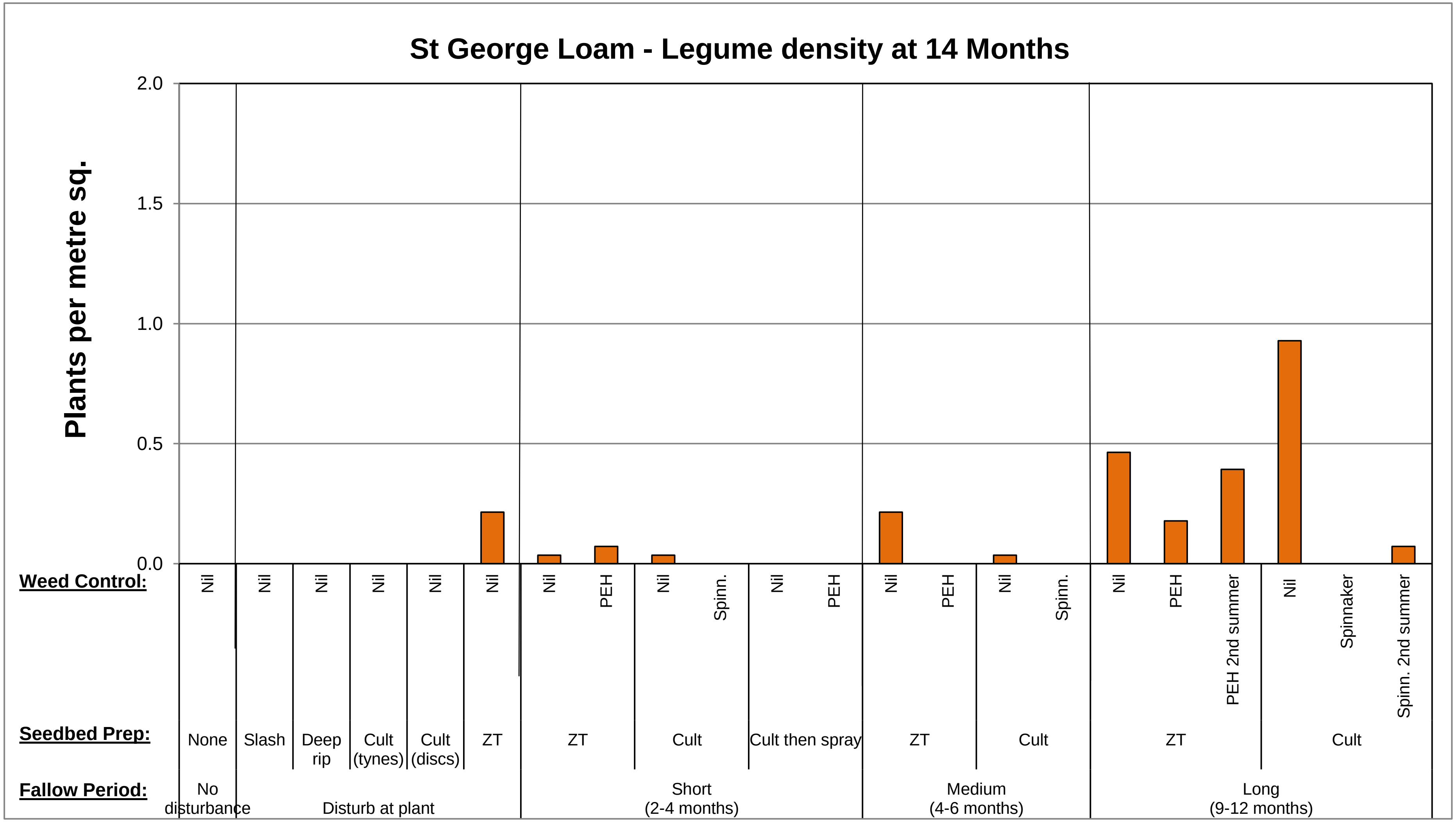

Fig. 23: Legume plant density (plants/m2) at the St George loam soil legume establishment site 14 months after germinating rain. Data for this recording was not statistically analysed due to the extremely low numbers recorded (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

4.3.6 Pasture growth during the second summer (Approx. 12 months post emergence)

4.3.6.1 Trial dry matter results

Dry matter (DM) production one year after sowing has only been measured at Goondiwindi clay and Wandoan clay. Goondiwindi loam was not measured due to dry seasonal conditions resulting in very low DM production. St George experienced severely low rainfall resulting in most of the legumes dying. Wandoan loam was severely impacted by wildlife (bettongs).

Goondiwindi clay provides the largest range of treatments of the two sites where DM was measured and is shown in Fig. 24. There is a very clear trend where treatments that controlled the grass to a greater extent produced more legume, conversely the greater the grass production the less legume. That is, longer fallows with greater post emergence weed control produced more legume. By contrast, the grass production was greatest in the no disturbance or disturb at plant treatments and lowest in the long fallows.

No disturbance of the existing grass or one pass treatments failed to produce meaningful amounts of legume (from either a grazing animal diet or nitrogen input to the pasture point of view). Medium length fallows produced intermediate results in both grass and legume DM.

These results clearly demonstrate that in the year of establishment, in moisture limiting environments with highly competitive existing grass pastures, there is a clear trade-off between grass growth and legume growth. Graziers in effect have the choice of keeping the grass or establishing the legume reliably, trying to have both grass and legume is a trade-off.

The poor long term legume establishment from low DM production in the no-disturbance or disturb at plant treatments is likely to be exacerbated under grazing through preferential grazing. A low density of small plants is likely to result in high grazing pressure per individual plant, whereas with higher plant numbers grazing pressure will be spread across individual plants allowing a greater number to set seed. Grazing was excluded from these trials during summer with grazing occurring through winter.

Some specific points from the results in Fig. 24 include:

- Fallow length had a big impact on legume DM. DM from highest to lowest was long fallows>medium fallows>disturb at plant or no disturbance.
- Grass DM was the reverse of legume DM, that is grass DM from highest to lowest was no disturbance>disturb at plant >medium fallow>long fallow.
- Spinnaker treatments produced significantly more legume DM in the long cultivated fallow treatments. Long cultivated fallows without Spinnaker treatments had much higher amounts of broadleaf weeds. This effect is likely to be higher on soils with higher weed loads.
- Post emergence herbicides in the long ZT fallows showed a non-significant trend towards higher legume DM.
- Long fallows that had no post-emergence weed control applied had significantly higher weed DM.
- The long fallows with medic treatments produced comparable amounts of legume DM as the long fallows. It is therefore possible to establish medics in winter followed by summer growing legumes in the following summer.

4.3.6.2 Ramifications for establishing legumes in strips

Pastures require both grass and legumes to be productive in the long term. If a paddock already has competitive grass pastures, graziers are often reluctant to kill them and forego grazing for a period to establish a legume. The DM production from the trials suggest that using fallowed strips could be a useful compromise to more reliably establish the legume while reducing foregone income.

The long fallows produced four to five times more legume DM than the medium fallows. If 20 – 25% of a paddock (e.g. 5m fallowed strip on 20-25m centres) were to be established in long fallowed strips, it is capable of producing as much legume per hectare as would be produced through ploughing out the whole paddock for a medium length fallow.

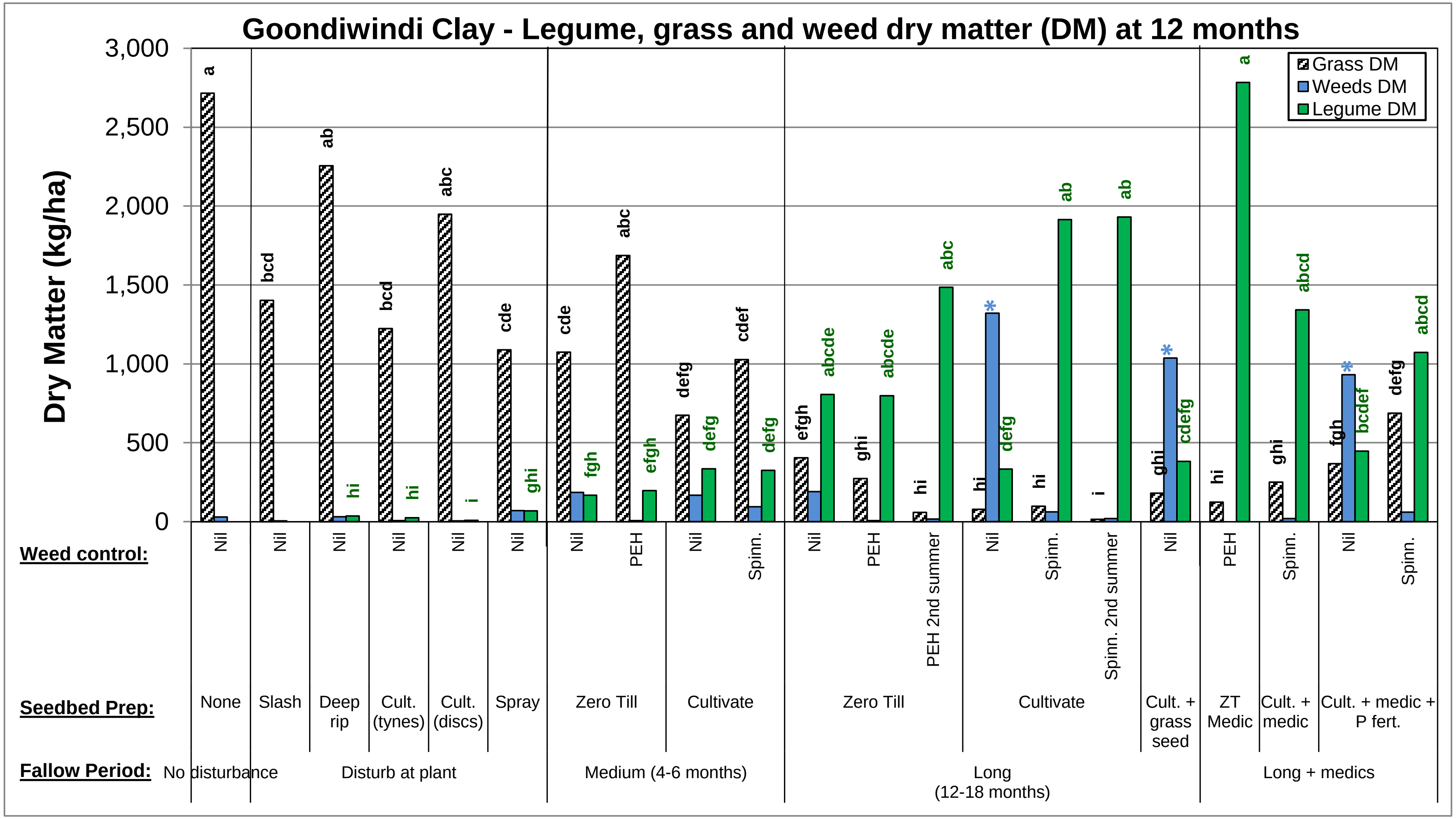

Fig. 24: Grass, legume and weed dry matter at the Goondiwindi clay soil legume establishment site, 14 months after germinating rain. Significance notation is for comparison within dry matter fractions. Treatments with significantly higher weed burden than all other treatments are marked with an asterisk. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

4.3.7 Pasture growth out to three years at Wandoan

Only the Wandoan clay site has been measured for 2-3 years after sowing. The trial sites at Goondiwindi and St George will continue under a new project with MLA ("Legume best management practices in the Brigalow Belt bio-region").

An important consideration for interpreting these results is that this trial site did not include long fallows. There was also a mechanical issue that may have reduced the effectiveness of the Spinnaker treatments.

4.3.7.1 Legume establishment

Legume density is shown in Appendix Fig. 45. All treatments showed a decline in legume density over the first year. Only a few treatments, notably Spinnaker treatments, have increased legume density from the low point at one year after sowing. Four legume plants/m^2 has been considered the bench mark of adequate legume density for these pastures. The no disturbance and cultivation at plant treatments still have low plant numbers three years after sowing (i.e. <4 plants/m^2). All of the fallowed treatments and Glyphosate at plant treatment have approximately 4 plants/m^2 or higher.

Legume dry matter at one, two and three years is shown in Fig. 25. No disturbance and cultivate at plant treatments show reduced dry matter production reflective of their low plant density. Only a few treatments are showing significantly higher DM production, notably both Spinnaker treatments at year one and the short fallowed Spinnaker treatment in years two and three. Unfortunately one of the medium fallow period Spinnaker treatment reps was very heavily impacted by grazing which has likely contributed to its lower productivity relative to the short fallow treatment in year 2 and 3. The Spinnaker treatments and the spray plus cultivation treatment were observed to have better control of the grass than other treatments.

The spray with Glyphosate at plant treatment has produced much better legume numbers and dry matter production than other one-pass operations. Presumably this means the herbicide provided a greater reduction in grass competition than one-pass cultivation treatments. The spray treatment achieved an unusually high control of the buffel grass pastures compared to other trial sites due to the pasture being lush, green, leafy and actively growing with very little standing dead stem to intercept the herbicide. The trial then received very good germinating rain and follow up before winter which is ideal for this sort of treatment that had not stored soil moisture (i.e. it is reliant on follow-up rain). Based on these results, spraying may provide a better chance of legume establishment than one pass cultivation. However, the one year legume DM results at Goondiwindi from a drier year for this treatment suggest that this treatments lack of stored moisture at sowing will mean it is a less reliable and lower productivity technique then using fallows.

4.3.7.2 Grass production

Grass dry matter production over three years for the Wandoan clay trial site is shown in Fig. 26. There were no significant differences in grass dry matter between treatments in any year. However there is a trend where fallowed treatments have produced more DM two and three years after sowing perhaps due to a renovation effect.

The grass DM results are interesting in that even in treatments where cultivation or herbicides were used to try to kill the grass for up to six months, as well as with post-emergence herbicides for some treatments, there is as much grass being produced as where the pasture was not disturbed. The pasture in the fallow treatments was observed to have a lower basal cover of grass but it was not measured. These results suggest that graziers can fallow their buffel grass pastures for a medium length fallow (up to 6 months) and still have buffel grass recolonise from the soil seed bank, especially if fallowed strips were used as the buffel will recolonise from the adjacent pasture. Unfortunately there were no long fallows at this trial site, the Goondiwindi trial will provide data on the impact of long fallows on the recolonization of buffel grass. Further studies would be required to test other sown grass pastures ability to recolonise fallowed strips or whole paddocks.

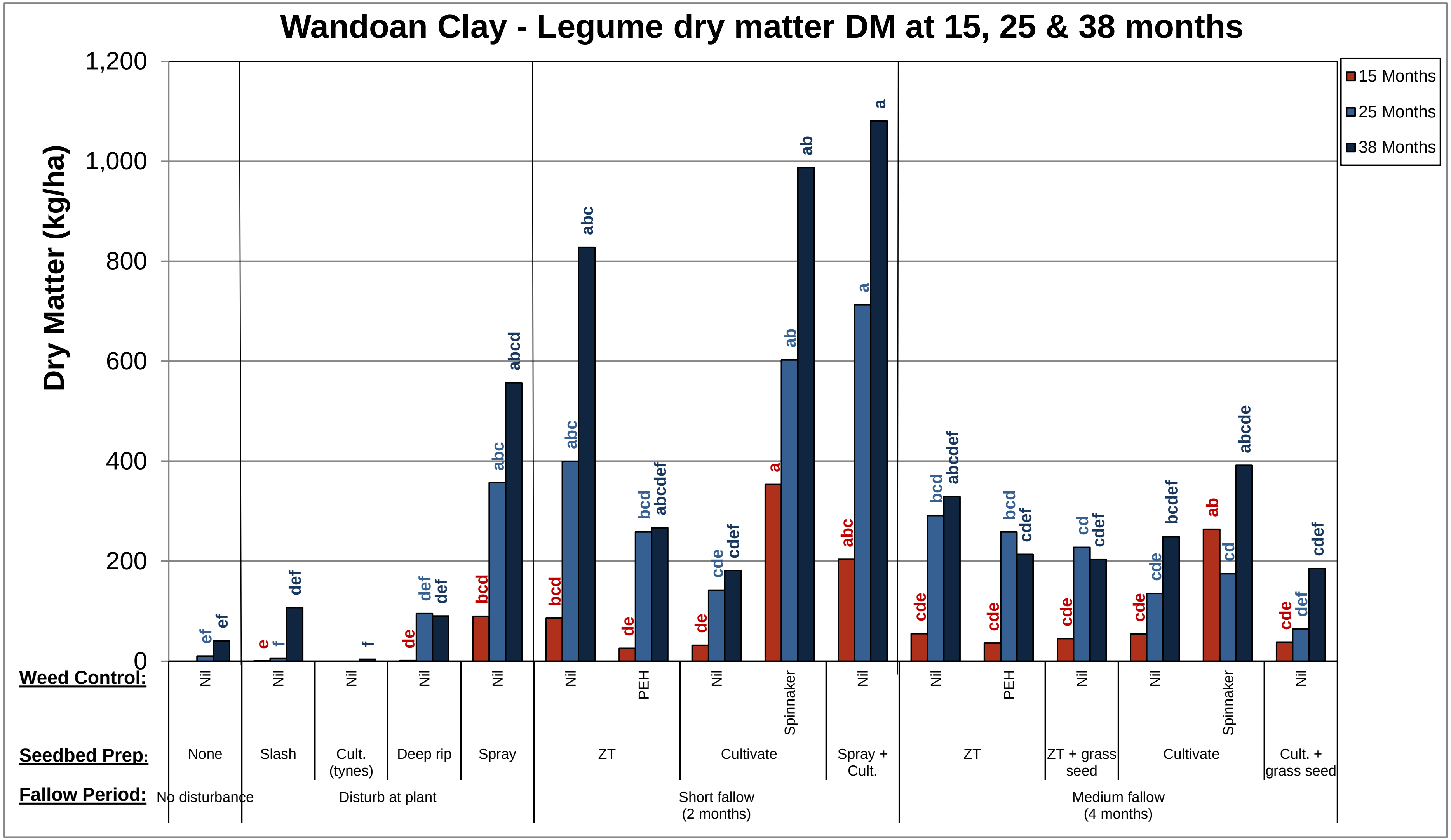

Fig. 25: Legume biomass (kg/ha) at the Wandoan clay soil legume establishment site 15, 25 and 38 months after germinating rain. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

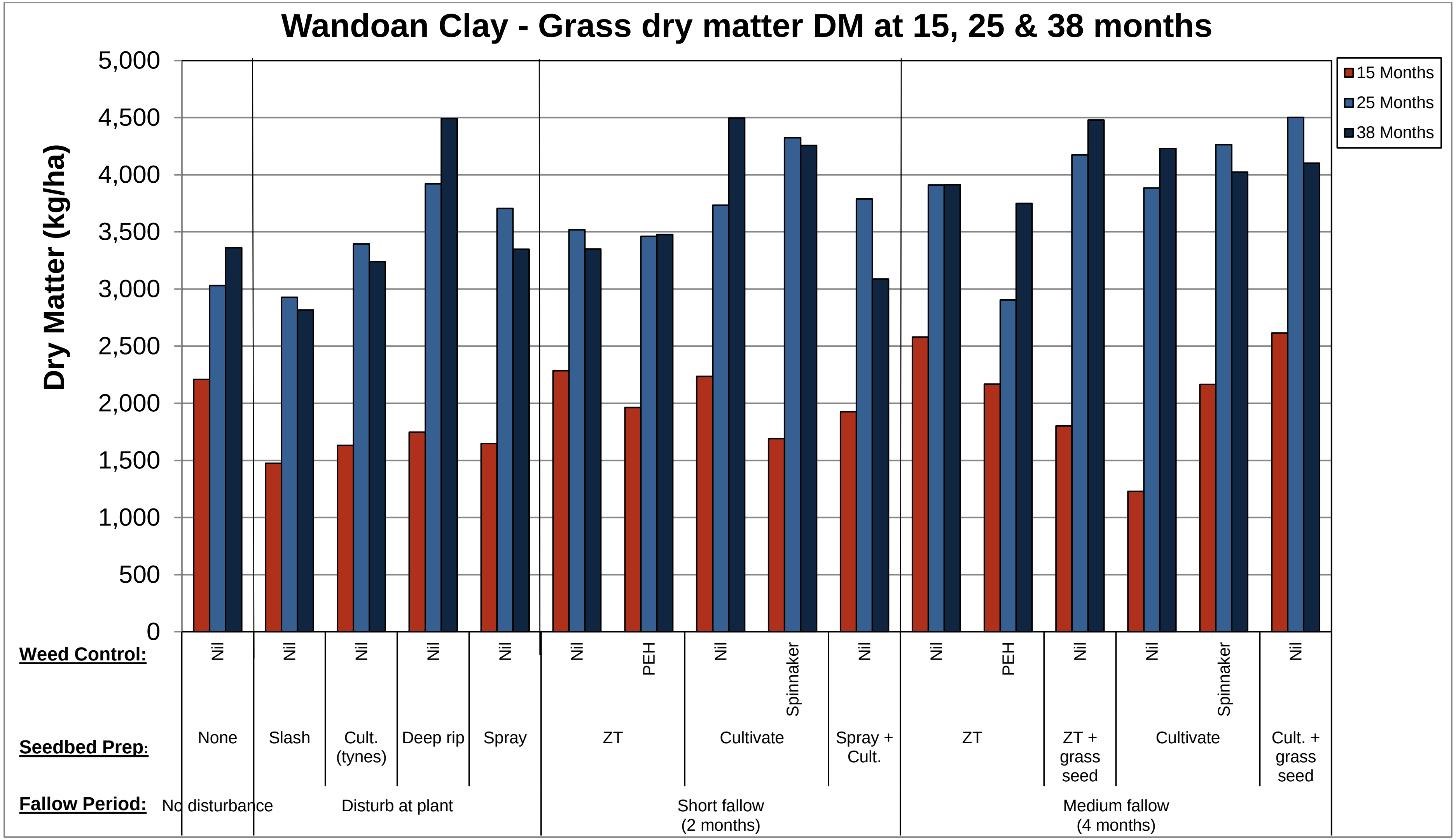

Fig. 26: Grass dry matter (kg/ha) at the Wandoan clay soil legume establishment site 15, 25 and 38 months after germinating rain. No statistical differences were recorded within any recording period (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

4.3.8 Herbicides for post-emergence weed control

The selective post emergence herbicides used in these trials showed some short term negative impacts in the first three months on legume growth at a couple of sites as well as positive impacts at others. In the first few months growth, negative impacts that were observed were:

- At the Goondiwindi clay trial site, visual damage from Spinnaker was observed on desmanthus. Despite the visual damage there was no reduction in plant numbers or height.
- At St George clay trial (Appendix 1):
  - Spinnaker reduced desmanthus density in the long fallows. There was also a reduction in the plant numbers in the medium length fallows but not significant ($P<0.05$).
  - Post emergence herbicides (PEH) (Verdict and Basagran) show a trend towards some suppression of plant numbers in the long and medium fallows but it was not a significant reduction ($P<0.05$).

Spinnaker and post-emergence herbicides showed no negative impact on early growth at other sites and in cases where a negative impact was visually observed in the short term, there were longer term benefits from the herbicides (i.e. from reducing weed competition). For example, over the first year of growth, using Spinnaker resulted in significantly higher legume density at the Goondiwindi loam site for both long and medium fallows; post-emergence herbicides on the zero tillage treatments showed a non-significant trend towards higher plant numbers (Fig. 21). In contrast, at the clay site there was no benefit in legume number from using Spinnaker or PEH (on the ZT treatments) (Fig. 36), however there was improvement in legume DM production (Fig. 24). This difference between soil types most likely reflects a higher level of weed competition at the loam site.

The results from the trials suggest that the selective post emergence herbicides can be very useful at improving legume growth through reducing weed competition but that they can cause some damage to the legume seedlings. The trade-off when using these herbicides is whether the damage from weed and grass competition is greater than herbicide impacts.

The results from both sites that have measured DM production suggest that legume growth over the first year is likely to be improved through the use of selective post emergence herbicides. Further R&D is required to clarify the application recommendations to justify gaining approvals for these herbicides to be used on these legumes.

Fig. 27: Desmanthus seedling with suspected spinnaker damage and stunting 4 weeks after germinating rain at the Goondiwindi clay soil establishment site. Plants were stunted, bluish in colour and had leaves partially closed.

4.3.9 Establishing medic prior to summer growing legumes

Planting was delayed by a year at the Goondiwindi trial site due to drought which allowed the inclusion of some additional treatments to test whether it is possible to establish medics during winter and summer growing legumes the following summer. Medic growth was measured during the first winter and is shown in Fig. 28 and Fig. 29. The subsequent growth of the summer growing legumes (desmanthus and Caatinga stylo) is shown for the clay soil trial in Fig. 24.

On both soil types, total plant population and biomass were significantly improved with direct drilling of seed as compared to broadcasting. On the loam soil, drilling increased average populations by between 519 and 1,900% above those recorded in broadcast treatments and improved biomass by between 144 and 315%. On the clay soil, drilling increased populations by between 339 and 983% above those measured in broadcast treatments. Clay soil drilling showed biomass improvements of between 124 and 1,368%. Loam soil broadcasted legume populations were significantly higher on cultivated seedbeds as compared to zero-till seedbeds. Cultivation, in combination with Spinnaker® post-emergent weed control produced significantly higher legume populations than all other loam soil treatments. No significant biomass or legume population seedbed preparation treatment effects were observed on the clay soil. No significant seedbed preparation treatment effects were observed for yield on the loam soil.

Trial results suggest other possible interactions which may warrant further investigation. For example, on both soil types phosphorus application appears to benefit biomass production although not significant at the $P<0.05$ level. On the clay soil, Spinnaker® may have had an antagonistic effect on legume biomass and population. Neither of these observations are statistically verifiable with the existing data set, however given the limited degrees of freedom within the statistical analysis (3 for treatment and 4 for sowing method), future experiments could be better designed to investigate these factors further.

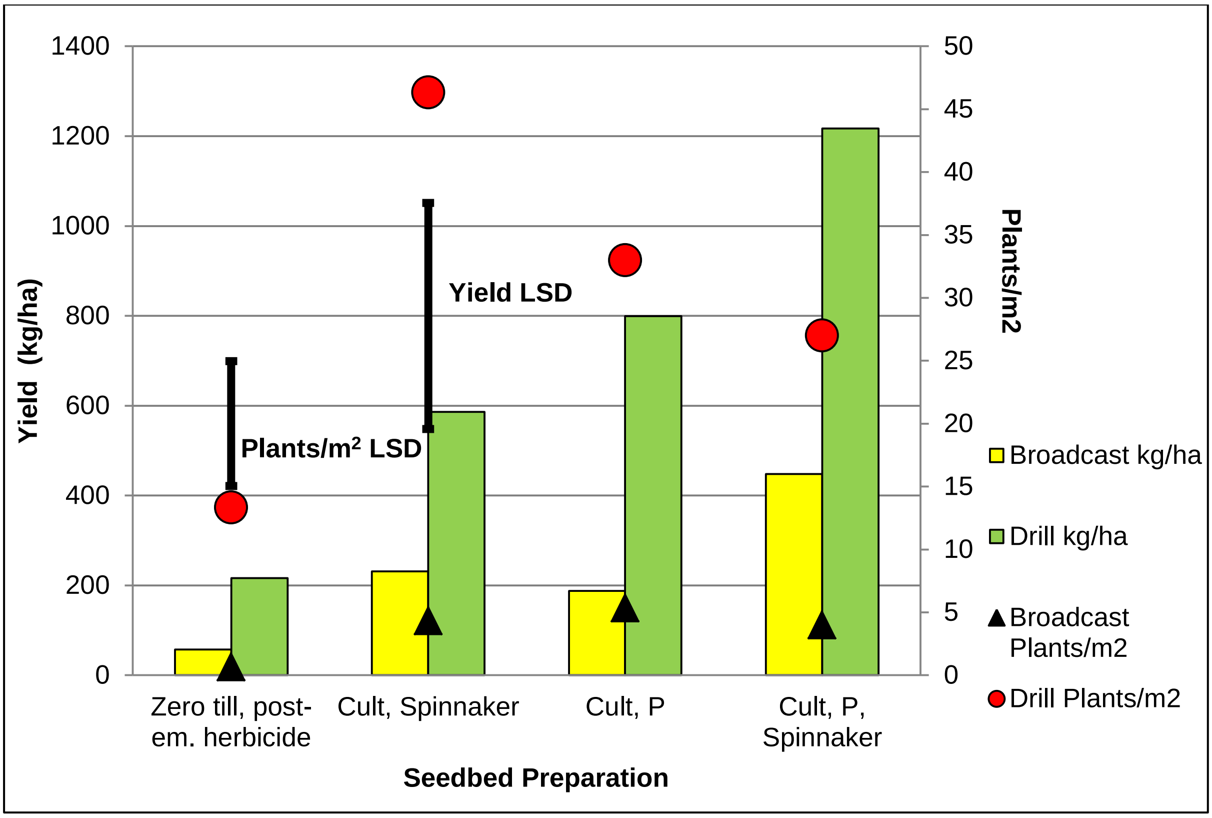

Fig. 28: Average total medic dry matter yield (kg/ha) and plant population (plants/m^2) responses to varying seedbed treatments at the loam site.

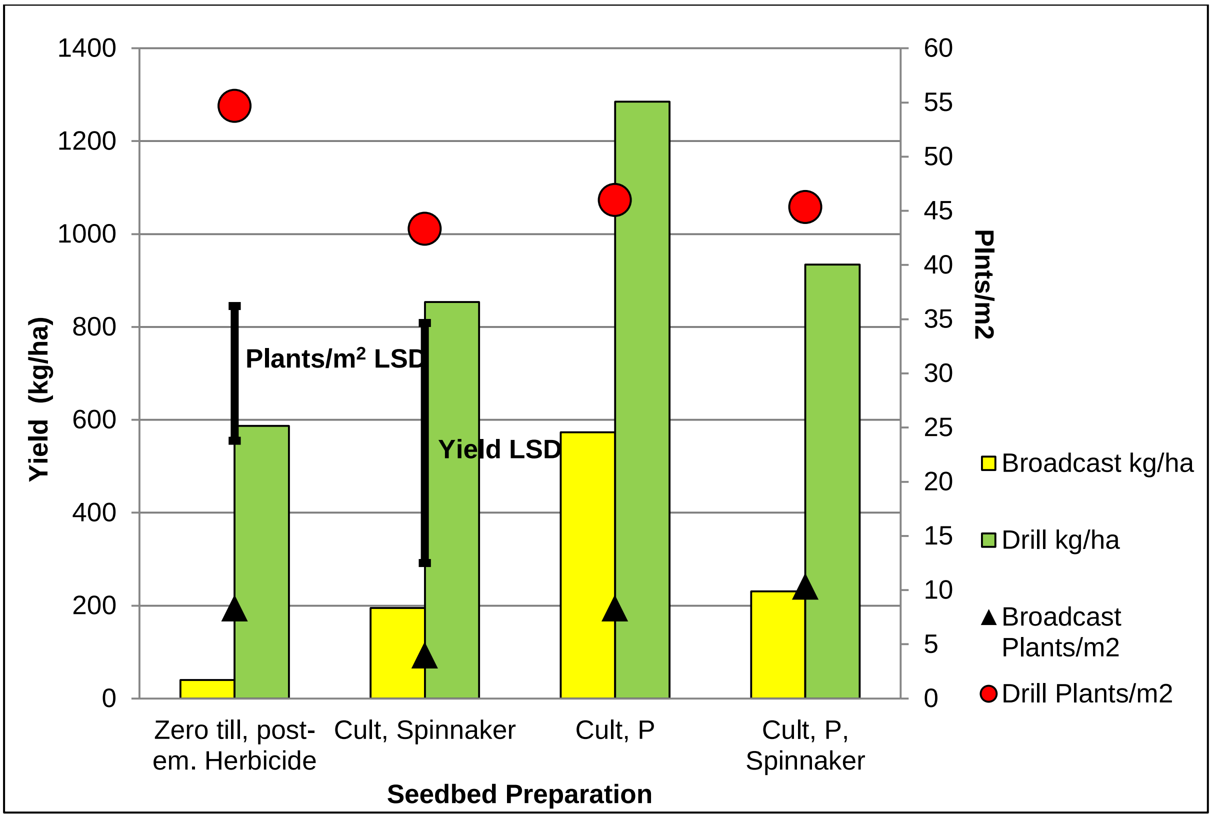

Fig. 29: Average total medic dry matter yield (kg/ha) and plant population (plants/m^2) responses to varying seedbed treatments at the clay site.

Medic growth was not measured during the 2016 winter (second winter), however the medic growth was observed to be much higher than the preceding winter due to more rainfall and higher seed loads from the previous year's medic growth. There was also a visual response to P fertiliser. These treatments also provided good desmanthus or Caatinga stylo growth one year after sowing.

These trial results demonstrate that it is possible to establish medics during winter and summer growing legumes during the following summer. Some additional considerations to achieving the establishment of both medic and summer growing legumes are:

- The medic needs to be sown first as it is an annual whereas the summer growing legumes are perennials which would preclude soil moisture storage if sown first.
- Being annuals, the medics must seed in the first winter and the pods allowed to stay on the surface and not be buried. Therefore, zero-tillage approaches are required to store moisture and control weeds between the medic seeding and the summer growing legumes being sown.
- Grazing management will need adjustment over time and in response to seasons allow both the summer and winter growing legumes to thrive.

4.4 Conclusions

4.4.1 Fallowing improves legume establishment

These trials demonstrate that legumes can be established reliably into existing grass pastures, even in dry years, using agronomic practices that are typically used for growing grain crops. Fallowing to store soil moisture, reduce the soil seed bank, and reduce competition from both grass and weeds is critical to minimise the impacts of the episodic rainfall events that are typical of the Brigalow Belt bio-region, thereby reducing seedling mortality rates.

Across all sites in these trials, increasing fallow period improved legume establishment. Even in wet years it is likely that at least some fallowing will improve establishment in this environment, but it is critical in average to dry years and in drier locations.

By contrast, the low cost, low reliability establishment techniques routinely used by graziers and recommended by farm advisors of broadcasting into existing pastures or one-pass cultivation failed at every trial site. No disturbance, slashing and one-pass cultivation treatments all failed to produce adequate legume density at all sites and should not be recommended as establishment techniques in this environment with competitive grass pastures.

One application of glyphosate at sowing produced better results than one-pass cultivation at Wandoan, showed promising early legume density and height but ended up producing similar results as other disturb at plant treatments at Goondiwindi and St George. These results suggest that spraying may be better than cultivation in wetter years, although to successfully establish legumes, this approach is completely reliant on follow up rain (i.e. it does not have significant amounts of stored moisture at plant). Timing is critical for spraying at plant to work effectively as the grass needs to be actively growing with good leaf area and few dead stalks or leaves to get good control of the grass, followed by good germinating rains to compensate for the lack of stored soil moisture.

4.4.2 Post emergence herbicides

These results suggest that under some circumstances, the herbicides can cause some damage to the legume seedlings. The trade-off is whether the damage from weed and grass competition is greater and therefore minor damage from the herbicide in the short term gives greater growth in the subsequent season.

The results from these trials suggest that selective herbicides that can be used post legume emergence to control grasses and broad-leaf weeds can produce dramatically better legume growth through reduced weed competition. For example, at one of the trials the herbicide treatments with long fallows produced two to five times as much legume dry matter as without the herbicide. However, the herbicides also damaged legume seedlings at some sites in the short term, albeit not as much as the damage caused by weed competition in the longer term. Further research is required to develop better application recommendations for these herbicides.

4.4.3 Drilling versus surface broadcasting seed

Drilling seed produced better legume density than broadcasting seed where it improved seed to soil contact (i.e. on firmer surfaced soil). Drilling is more likely to be beneficial with:

- Soil types where the soil surface is firm, that is crusting, hard setting or firm soil surfaces.
- Zero tillage compared to cultivated fallows or cultivated planting operations.
- Prior management that has allowed the soil surface to become firm (e.g. the medic treatments at Goondiwindi).
- Very dense pasture cover which reduces the chance of broadcast seeds contacting the soil surface.

Drilling produced no benefit on the cracking clay soil trial sites that had self-mulching surfaces without excessive pasture cover. Drilling produced negative results where seed was sown too deep. Drilling of small seeded legumes should not be attempted unless planting equipment allows very good control of sowing depth.

4.4.4 Sowing legumes in strips

Pastures require both grass and legumes to be highly productive in the long term. If a paddock already has productive grass pastures, graziers are often reluctant to kill them and forego grazing for a period to establish a legume. The DM production from the trials suggest that using fallowed strips could be a useful compromise to more reliably establish the legume while reducing foregone income.

At the site where DM production was measured at 12 months (Goondiwindi clay), the long fallows produced four to five times more legume DM than the medium fallows. Therefore if 20 – 25% of a paddock (e.g. 5m fallowed strip on 20-25m centres) was established in long fallow period strips, it is capable of producing as much legume per hectare as would be produced if the whole paddock was ploughed out for a medium length fallow.

5 Legume rate of spread trials

5.1 Introduction

Establishing legumes in fallowed strips into existing grass pastures is seen as a sensible approach to improve the reliability of establishing legumes while reducing the loss of grazing opportunity in the short term. If legumes are established in strips within commercial pastures, a key question is "what is the rate of spread of the legume"? Or said another way, "how long will it take for the legume to colonise the remaining grass strips"? The rate of legume spread will influence the decision about how far apart fallowed strips should be to allow establishment across a whole paddock within a reasonable amount of time.

Trails were established across a range of locations to test the rate of spread of Caatinga stylo and Progardes desmanthus into existing buffel grass pastures.

5.2 Methodology

Two different trial types were used to test the rate of legume spread into existing grass pasture:

- "Wagon wheel" trials.
- Opportunistic measurement of legume demonstration trials with graziers.

5.2.1 "Wagon wheel" trials

The wagon wheel trials were co-located with the establishment trials (Fig. 1). Two trials were established near Goondiwindi, two near St George and one near Wandoan. The trials design is based on a variation of the "Nelder wheel" where legume strips are established like the spokes of a wagon wheel radiating out from a central point. This design allows the measurement of an ever increasing distance between legumes established in strips (Fig. 30).

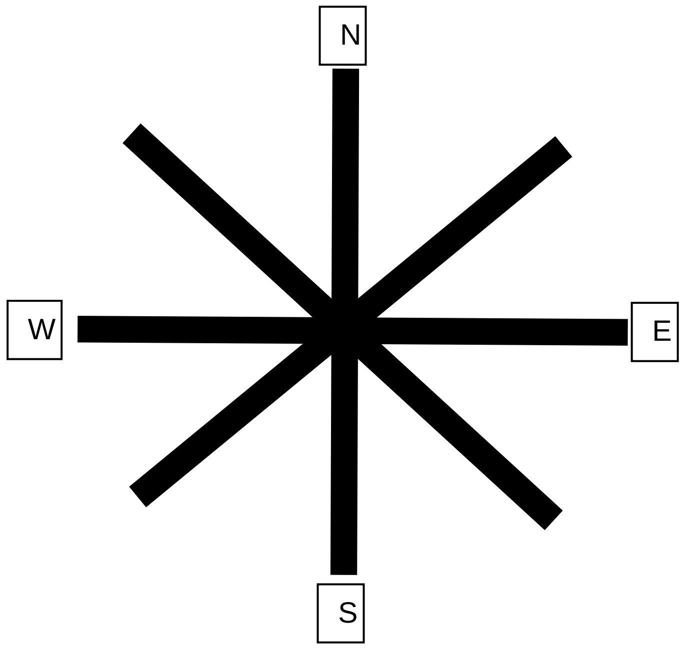

Fig. 30: "Wagon wheel" trial design.

The trials established legumes into 5m wide cultivated strips with the aim of measuring to at least 50m between legume strips. To allow for tractor turning space, the design used a radius of legume strip of 90m.

The legumes were sown as a mix in all strips. The legumes sown were Caatinga stylo (cv. Primar and Unica) and desmanthus (cv. Progardes).

5.2.2 Demonstration planting of legumes in strips

An on-farm research site near Moura that is testing establishing desmanthus and Caatinga stylo in strips is being used to test the rate of spread of these legumes into existing buffel grass pastures. The legumes were established in twin rows 1m apart in the centre of 5m cultivated fallowed strips. The centre of the fallowed strips are 10m apart. Legume density away from the original twin rows has been measured over time.

The legumes were planted in separate fallowed strips. The varieties in different strips were:

- Caatinga stylo cv. Primar
- Caatinga stylo cv. Unica
- Desmanthus cv. Progardes (a blend of five varieties from three species).

5.3 Results/discussions

5.3.1.1 Wagon wheel trials

The wagon wheel trials have been sown at all locations. The Goondiwindi and Wandoan sites had sufficient legume establishment, however the Caatinga stylo has been preferentially grazed by wildlife which has favoured the growth of desmanthus. Unfortunately the St George sites need to be re-sown as the drought conditions have resulted in inadequate plant density.

The wagon wheel trials have not been established for a sufficiently long period to allow the legumes to spread.

5.3.1.2 Demonstration planting of legumes in strips

The density of the legumes at 0-1m, 1-2m and 2-3m from the original sown row approximately 18months after sowing is shown in (Fig. 31). There is extremely high legume density at 0-1m from the original row, moderate number at 1-2m and very few plants beyond 2m. The grass at the edge of the fallowed strips starts at 2-2.5m from the original row, therefore seedlings were competing against established grass plants at this distance and greater.

Preliminary results are encouraging that these legumes can spread from rows planted in fallowed strips to the edge of the grass strip over one year's growth. The true test comes when these legumes start competing with the existing grass. This site will be measured to test spread into the grass in coming years.

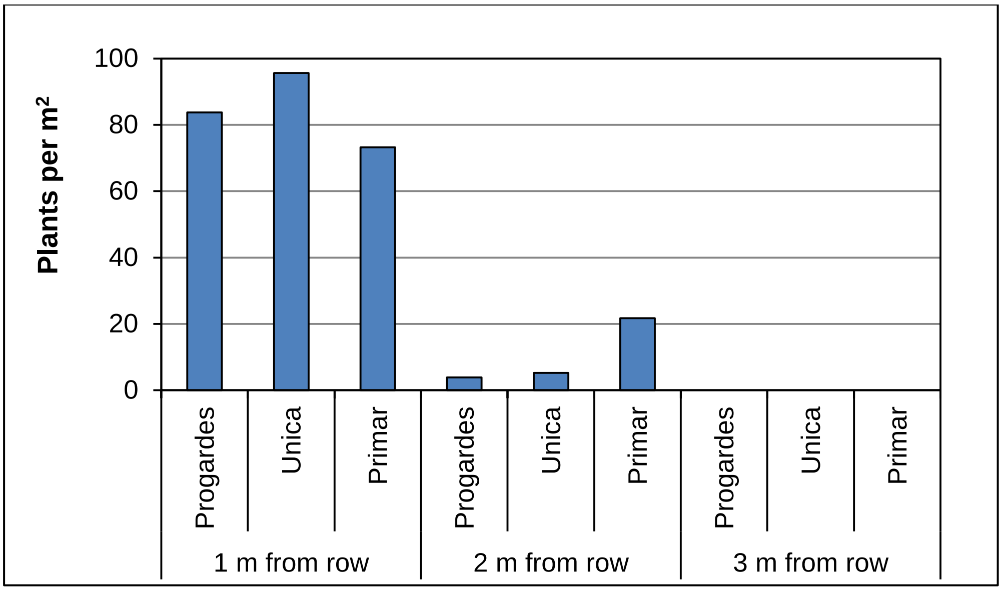

Fig. 31: Legume density at different distances from the original row approximately 18 months after sowing.

Fig. 32: Example of legume rate of spread monitoring point at the Theodore site. Individual plant emergence will be documented over time along transects running 90 degrees into the grass inter-row. (Top photo Caatinga stylo. Bottom photo desmanthus. Difference in greenness is due to photos being taken on different dates).

6 Conclusions

Commercial results from incorporating legumes into existing sown grass pastures in the sub-tropics have been poor, with poor establishment being the most common reason for legumes failing. Although good establishment is recognised as being critical to the long term persistence and productivity of pasture legumes; most graziers routinely use low cost, low reliability techniques when trying to establish legumes into existing grass pastures. The most commonly used and recommended establishment techniques are to broadcast seed into un-disturbed or burnt pastures; or one pass cultivation while seeding. These poor results have led graziers to view legumes as being risky and un-reliable.

The exception to the poor establishment described above is leucaena. When establishing leucaena, graziers routinely use grain cropping agronomic techniques which has taken leucaena from being considered the riskiest legume to establish to being the most reliable. The willingness to use improved agronomy when establishing leucaena probably reflects that it is a more mature technology, it does not increase in density over time (if well managed) and the perception that it's persistence and productivity warrant the additional effort and cost.

The lack of willingness to spend more on establishing small seeded legumes like desmanthus and Caatinga stylo is probably at least partially due to the perception that they are not productive enough and the risk of failure is too high to warrant the cost. In trials described in Volume 3 of this report, desmanthus and Caatinga stylo have been demonstrated to be highly productive and they have both outperformed leucaena for long term persistence, and therefore productivity, at several pasture evaluation sites.

Establishment trials conducted as part of this project have shown that establishing small seeded legumes like desmanthus and Caatinga stylo can be a lot more reliable if good agronomic practices are used. Key principles or considerations for reliable legume establishment in existing grass pastures are:

- Legume seedling access to moisture and other nutrients.
- Good seed to soil contact.
- Establishing legumes in strips or across whole paddocks.

6.1 Legume seedlings need access to moisture (and other nutrients)

Legume seedlings need good moisture supply for rapid early growth to be large enough to cope with the stresses of dry seasonal conditions and winter to limit mortality as well as produce forage for livestock. Seedlings are more prone to these stressors because of their small root systems. In particular there needs to be enough water when seedlings are very small to survive from the first germinating rain through to when follow up rain is received.

The supply of moisture can come from stored soil moisture and/or rainfall. The available water can either be used by the legume seedlings or through competing plants like the existing grass pasture or other weeds. Reliable legume establishment relies on more water being available more often and more of the available water being used to support legume growth.

6.1.1 Fallowing improves legume establishment

Fallowing to store soil moisture, reduce the soil seed bank, and reduce competition from both grass and weeds is critical to minimise the impacts of the episodic rainfall events that are typical of the Brigalow Belt bio-region, thereby reducing seedling mortality rates. Stored soil moisture via fallowing allows seedlings to survive and grow even in dry seasons.

Across all six trial sites, increasing fallow period improved legume establishment. The best legume establishment with the highest plant numbers and dry matter production occurred in long fallow period (9-12months) treatments. Even in wet years it is likely that at least some fallowing will improve establishment in this environment, but it is critical in average to dry years and in drier locations.

By contrast, the low cost, low reliability establishment techniques routinely used by graziers and recommended by farm advisors of broadcasting into existing pastures or one-pass cultivation failed at every trial site. No disturbance, slashing and one-pass cultivation treatments all failed to produce adequate legume density at all sites and should not be recommended as establishment techniques in this environment with competitive grass pastures.

One application of glyphosate at sowing produced better results than one-pass cultivation at two out of six trial sites, at the other four it showed promising early legume density and height but ended up producing similar results as other disturb at plant treatments. These results suggest that one-pass spraying may be better than one-pass cultivation in wetter years, although to successfully establish legumes this approach is completely reliant on follow up rain and therefore may be better suited to wetter districts closer to the coast or more monsoonal areas. Timing is critical for spraying at plant to work effectively as the grass needs to be actively growing with good leaf area and few dead stalks or leaves to get good control of the grass, followed by good germinating rains to compensate for the lack of stored soil moisture.

6.1.2 Rainfall

Rainfall patterns in the inland sub-tropics are such that there is a low likelihood of germinating rain combined with follow up rain before seedlings die in the absence of stored soil water and in the presence of competition by existing pasture. This contrasts with more monsoonal areas or “Mediterranean climate” areas where the shorter wet season means rainfall events are closer together. Growing grain crops in the sub-tropics relies on storing soil moisture, our trial results and graziers commercial experience suggest that reliable legume establishment also relies on stored moisture.

Follow-up rainfall is critical for legume seedling survival; however stored soil moisture increases the period that legumes can grow before being moisture stressed. Timing of sowing is therefore critical to maximise the chance of follow up rainfall. For most of Queensland’s sub-tropics, the highest rainfall months are January and February, which often also coincide with decreasing temperatures which reduces water demand by plants and evaporation. In some seasons the rainfall can come earlier but is often followed by hot dry weather with stored soil moisture therefore being critical to seedling survival.

Wetter districts closer to the coast and more monsoonal areas have a higher chance of receiving follow up rainfall and will therefore have a lower requirement for storing moisture during fallows.

Wetter years will also have less of a requirement for stored moisture, however predicting seasonal conditions 6-12months prior to summer to allow sufficient fallow periods has low predictive confidence. Given the challenges of predicting seasonal conditions, the recommendations for fallowing therefore remain but should be adapted to seasonal conditions. For example, if there is high amounts of stored soil moisture and/or the seasonal outlook is positive, then sowing earlier is likely to provide good legume establishment.

6.1.3 Grass and weed competition

The soil moisture stored during fallows and follow up rainfall can either be used by the legume seedlings or through competing plants like the existing grass pasture or other weeds. Competition from existing grasses and weeds is often the major influence on high seedling mortality. It is not the competition *per se* that kills seedlings; rather competition from existing vegetation may restrict growth to such an extent that seedlings subsequently die from moisture stress, temperature stress or acute nutrient deficiency. Survival depends on plant size when stress is encountered.

Controlling competition from the existing grass is best achieved through fallows. The results from the establishment trials showed that the longer the fallow period, the greater the control of both the existing pasture but also the soil seed bank. Within the same fallow period treatments, there can be a significant improvement in legume growth through controlling competition from re-colonising grasses and weeds via post emergence herbicides. For example, at one of the trials the herbicide treatments with long fallows produced two to five times as much legume dry matter as without the herbicide.

In the trials, the herbicides used were:

- For cultivated fallow treatments, Spinnaker was applied at plant (pre-emergent) to give residual control of grass and weeds.
- For zero-tillage fallows, Verdict was used for grass control and Basagran was used for broad-leaf control.

The trials also showed that the herbicides can cause damage to legume seedlings in some circumstances in the short term. Despite the short term damage, all the affected treatments ended up growing better than the comparison treatment without selective herbicide. These results suggest that the damage from competition from weeds is greater than the herbicide damage and/or the legumes grow out of the damage. Further trial work is required to develop better recommendations for using these herbicides with these legumes.

6.1.4 General recommendations

The general recommendations to balance soil water storage, follow up rainfall and competition for the in-land sub-tropics of Queensland from our trial results (and other trials) therefore are:

- Plant in January/February as this is the time of the year with higher rainfall, the greatest chance of follow up rain and less chance of extended heat waves after seedling emergence. Adjust to planting earlier if there is good stored moisture and/or the seasonal outlook is for a wet summer. If the paddock is in a cold location (e.g. a frost hollow on the Darling Downs) and planting summer growing legumes, earlier planting will allow plants to be larger before frosts occur and therefore survive the winter period better.
- Store sufficient soil water through fallowing.
    - Establishing in strips. In most districts on better soils that can store significant amounts of water, this is likely to mean long fallows of 9-12 month duration to maximise legume growth within the strips in order to maximise seed set and

spread in subsequent years. In wetter years or wetter districts or soils with lower water holding capacity this can be reduced to medium length fallows of 3-6months.
    - Planting whole paddocks. If planting the whole paddock there is a trade-off between grass and legume growth to maintain a balance in pasture composition. Medium length fallows of 3-6 months will allow grass to re-colonise from some remaining tillers or tussocks and from the soil seed bank.
- Control grass and weed competition. Where grass and weed loads are high, spraying with post emergence herbicides should result in significantly more legume growth. If establishing the legumes in strips, maximising the legume production through controlling grass and weeds is critical to facilitating high seed set and spread of the legume into the surrounding pasture. If planting across whole paddocks, there is a balance between allowing the grass to recolonise and controlling competition to the legume.

6.2 Good seed to soil contact

Seeds need to imbibe water via contact with moist soil to germinate. Practices that increase soil to seed contact when sowing can improve legume germination and growth. In the trials conducted in this project drilling seed produced better legume density than broadcasting seed where it improved seed to soil contact, for example on firmer surfaced soil. Based on the trials in this project and other trials, drilling is more likely to be beneficial with:

- Soil types where the soil surface is firm, that is crusting, hard setting or firm soil surfaces.
- Zero tillage compared to cultivated fallows or cultivated planting operations.
- Prior management that has allowed the soil surface to become firm (e.g. the medic treatments at Goondiwindi).
- Very dense pasture cover which reduces the chance of broadcast seeds contacting the soil surface.

Drilling produced no benefit on the cracking clay soil trial sites that had self-mulching surfaces without excessive pasture cover. Drilling produced negative results where seed was sown too deep. Drilling of small seeded legumes should not be attempted unless planting equipment allows very good control of sowing depth.

6.3 Establishing legumes in strips

Pastures require both grass and legumes to be highly productive in the long term. If a paddock already has competitive grass pastures, graziers are reluctant to kill them and forego grazing for a period to establish a legume. The DM production from the trials in this project suggest that establishing legumes in strips within existing grass pastures offers the compromise between cost, lost grazing and reliable legume establishment.

At the site where DM production was measured at 12 months, the long fallows produced four to five times more legume DM than the medium fallows. Therefore if 20 – 25% of a paddock (e.g. 5m fallowed strip on 20-25m centres) was established to legumes in long fallow (9-12months) strips, it is capable of producing as much legume per hectare as ploughing or spraying out the whole paddock for a medium length fallow (3-6months).

Fallowed strips need to be wide enough to allow soil moisture storage for legumes to be reliably established in strips. That is, fallowed strips need to be wide enough so that the grass roots do not extract the water by growing in from the edge during the fallow. To maximise moisture storage to depth in the soil requires fallow strips to be >6m wide.

Competition from the grass strips is greatest out to approximately 1m into the fallowed strips, therefore even in higher rainfall environments with a high likelihood of follow up rain require strips >2m.

Given the considerations above it is recommended that strips be >3m wide in the wetter parts of the Brigalow belt bio-region (e.g. the inland Burnett catchment, Callide district) as a minimum. In drier districts further inland, fallowed strips would need to be wider to allow for fallow moisture storage and the reduced likelihood of in-crop rainfall after sowing legumes. Strips in inland districts should be >6m wide.

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8 Appendix1: Better agronomy improves legume establishment

8.1 St George result

8.1.1 St George clay site

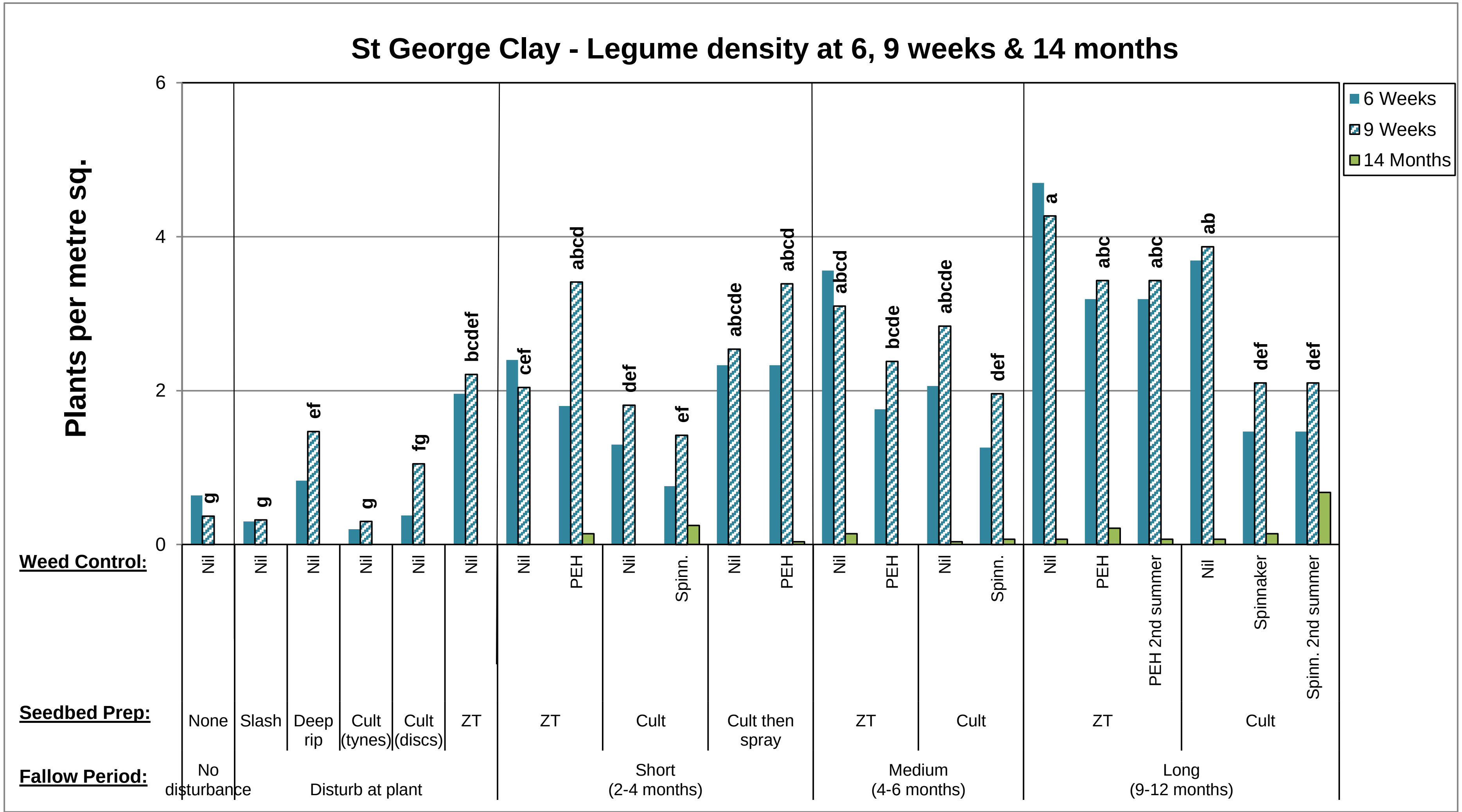

Fig. 33: Legume plant density (plants/m^2) at the St George clay soil legume establishment site 6 weeks, 9 and 14 months after germinating rain. Statistical differences presented for 9 week data. 14 month data was not statistically analysed due to the extremely low numbers recorded (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

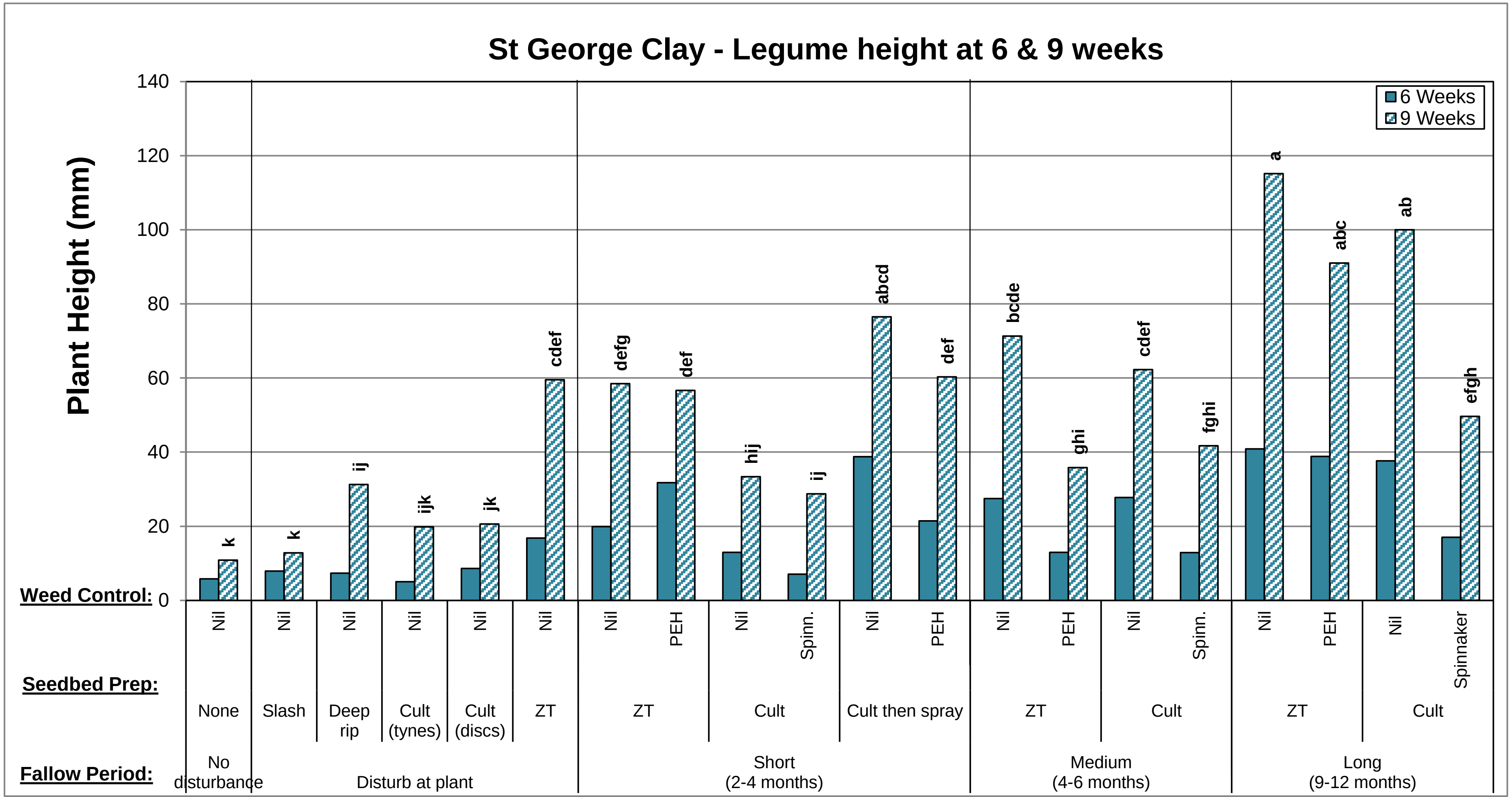

Fig. 34: Legume height (mm) at the St George clay soil legume establishment site, 6 & 9 weeks after germinating rain. Statistical differences presented for 9 week data (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.1.2 St George loam site

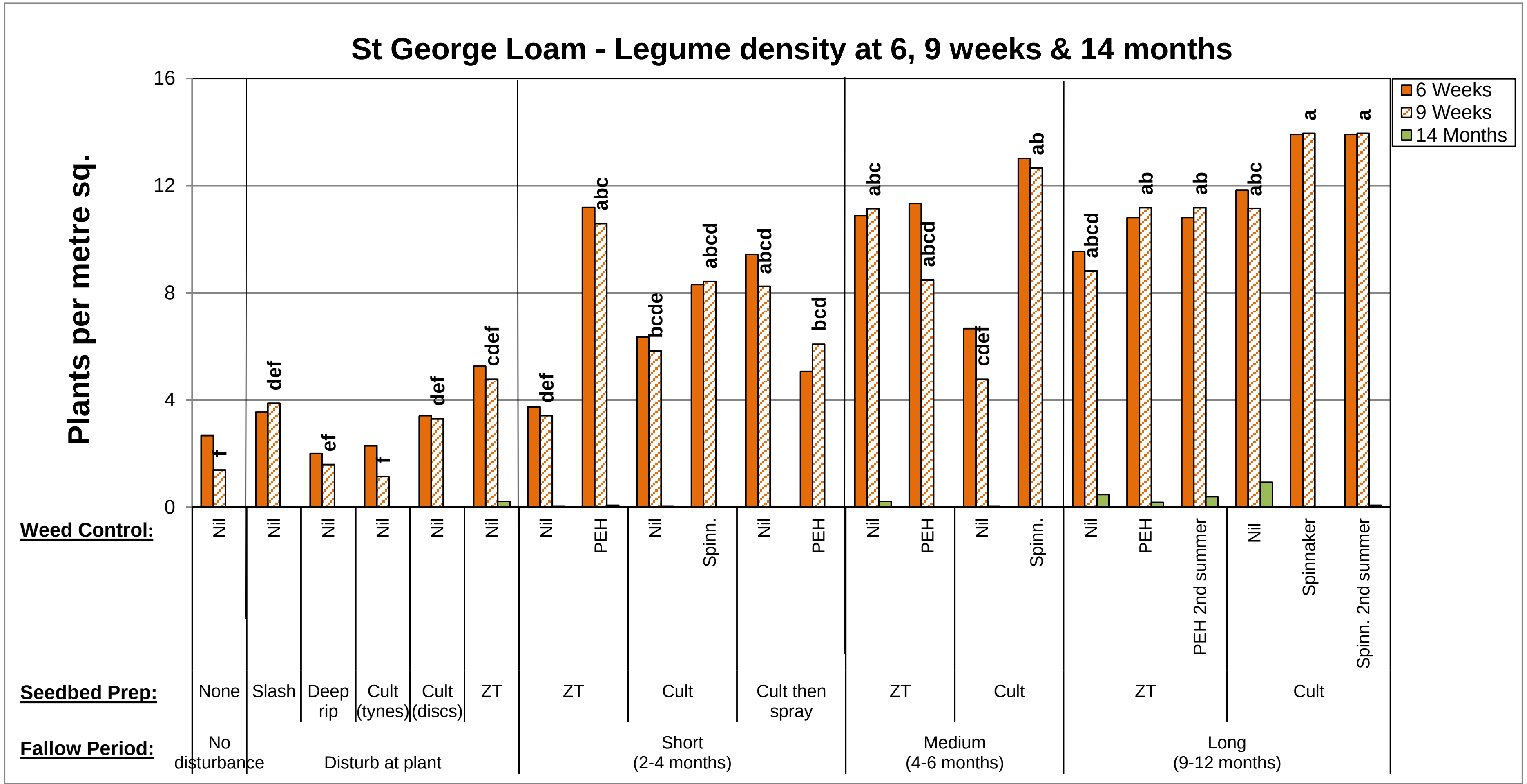

Fig. 35: Legume plant density (plants/m²) at the St George loam soil legume establishment site 6 and 9 weeks and 14 months after germinating rain. Statistical differences presented for 9 week data. 14 month data was not statistically analysed due to the extremely low numbers recorded (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.2 Goondiwindi results

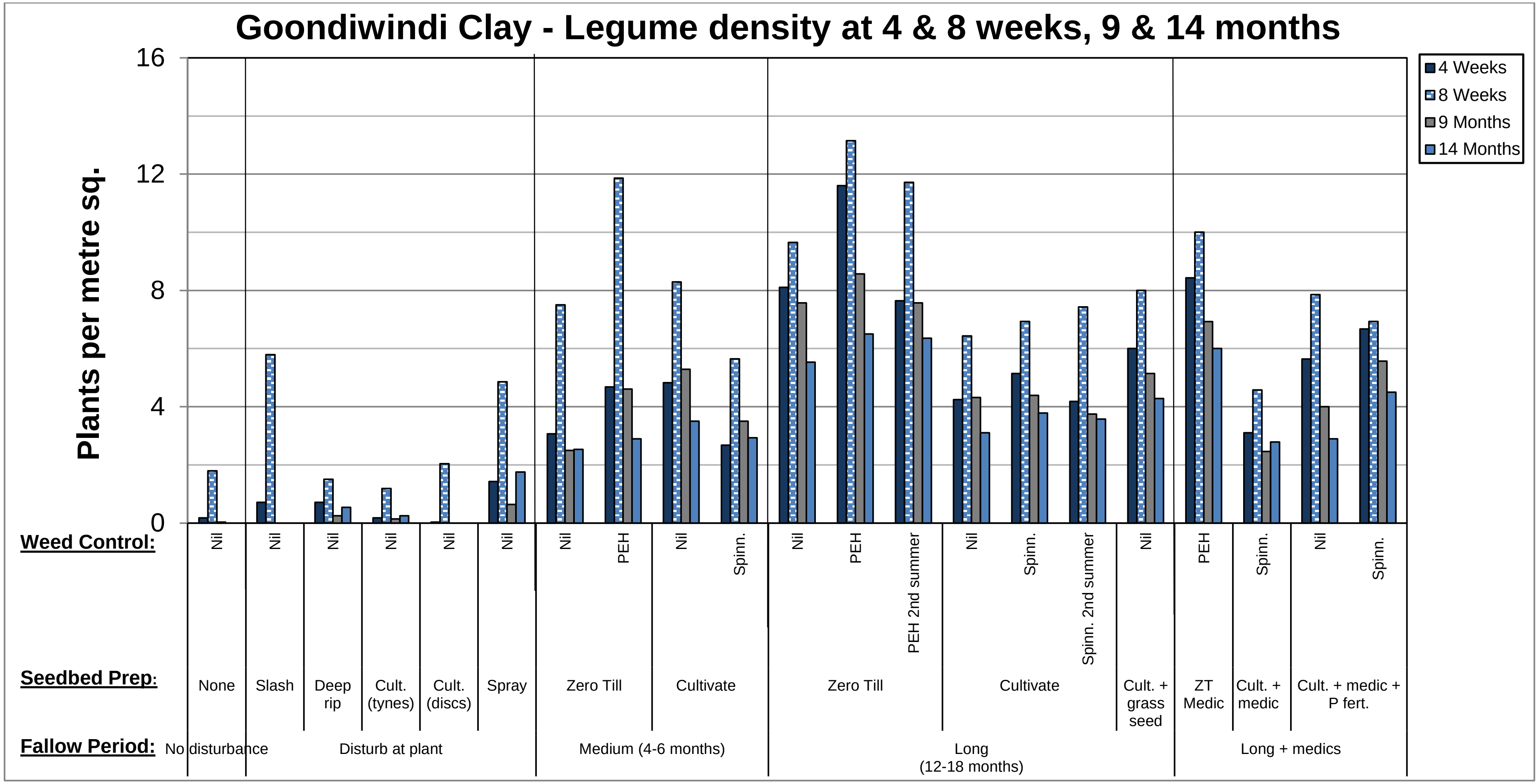

Fig. 36: Legume plant density (plants/m²) at the Goondiwindi clay soil legume establishment site 4 & 8 weeks, 9 & 14 months after germinating rain. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.2.1 Goondiwindi clay site

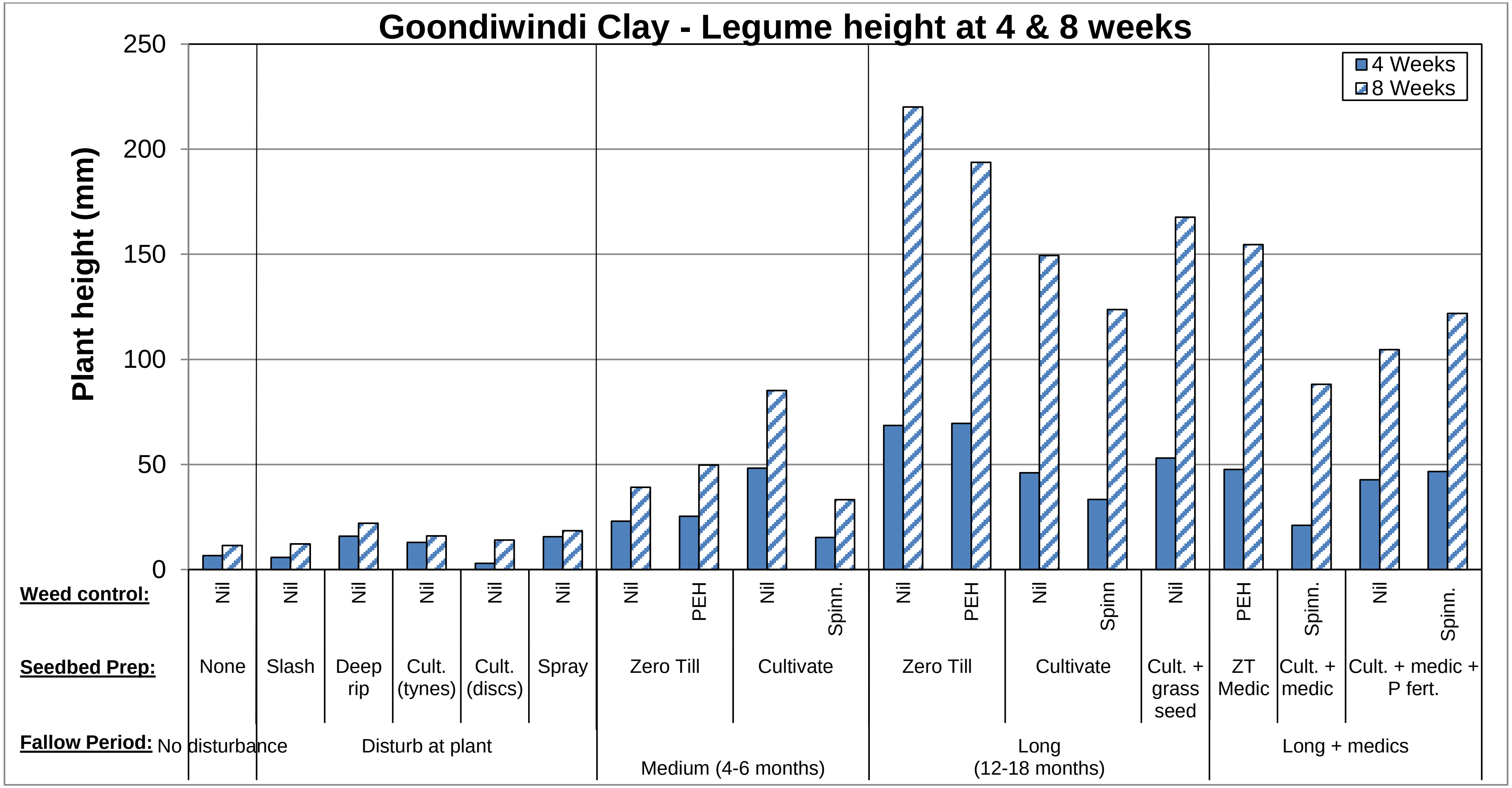

Fig. 37: Legume plant height (mm) at the Goondiwindi clay soil legume establishment site at 4 & 8 weeks. Significant effects were determined to the sowing level (i.e. broadcast and drill) and thus treatment significance values are not displayed. Sowing level significant effects can be found in Appendix Fig. 40 and Fig. 41 (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

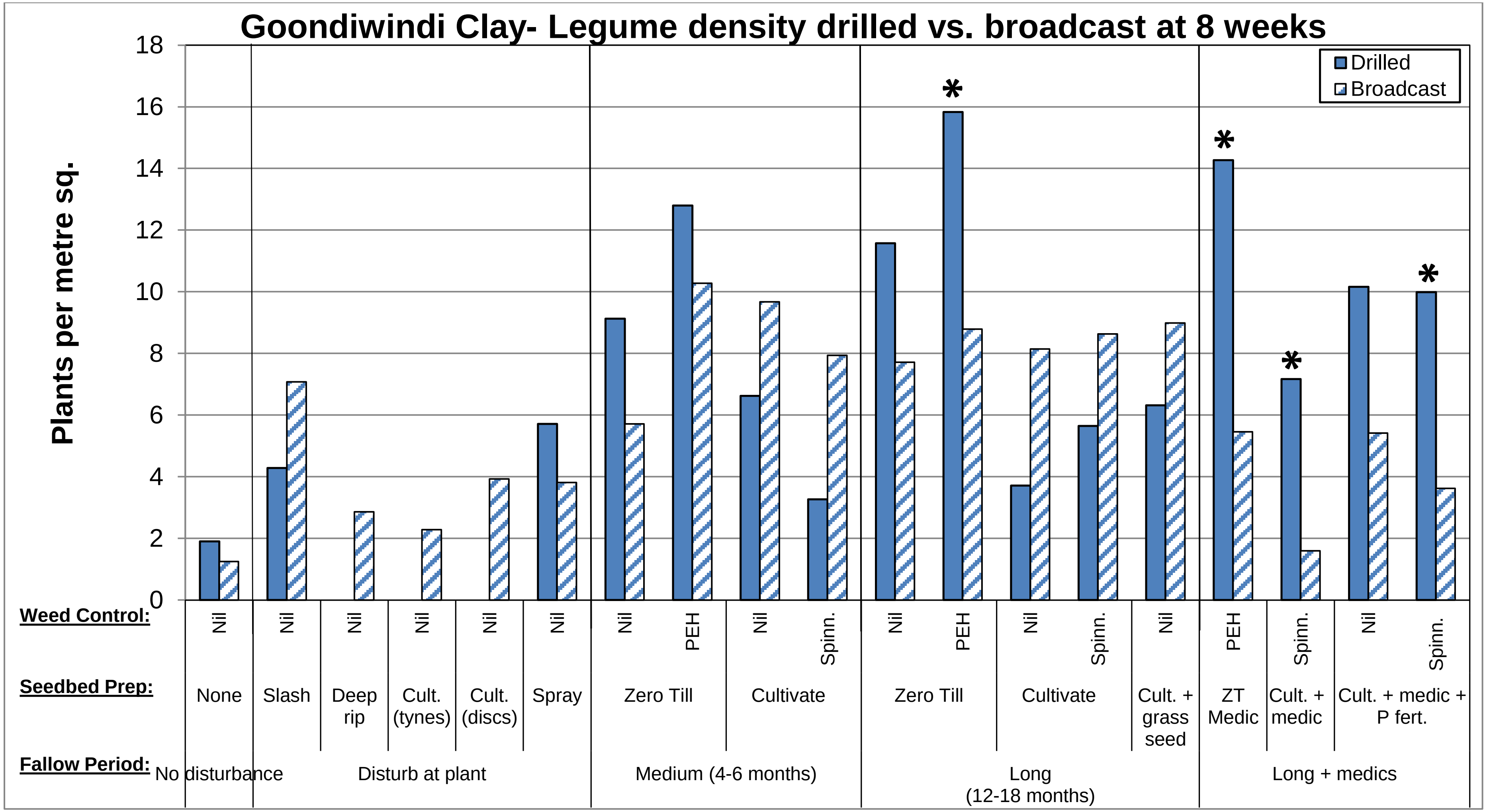

Fig. 38: Legume plant density (plants/m^2) at the Goondiwindi clay soil legume establishment site for drill and broadcast sowing methods, 8 weeks after germinating rain. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

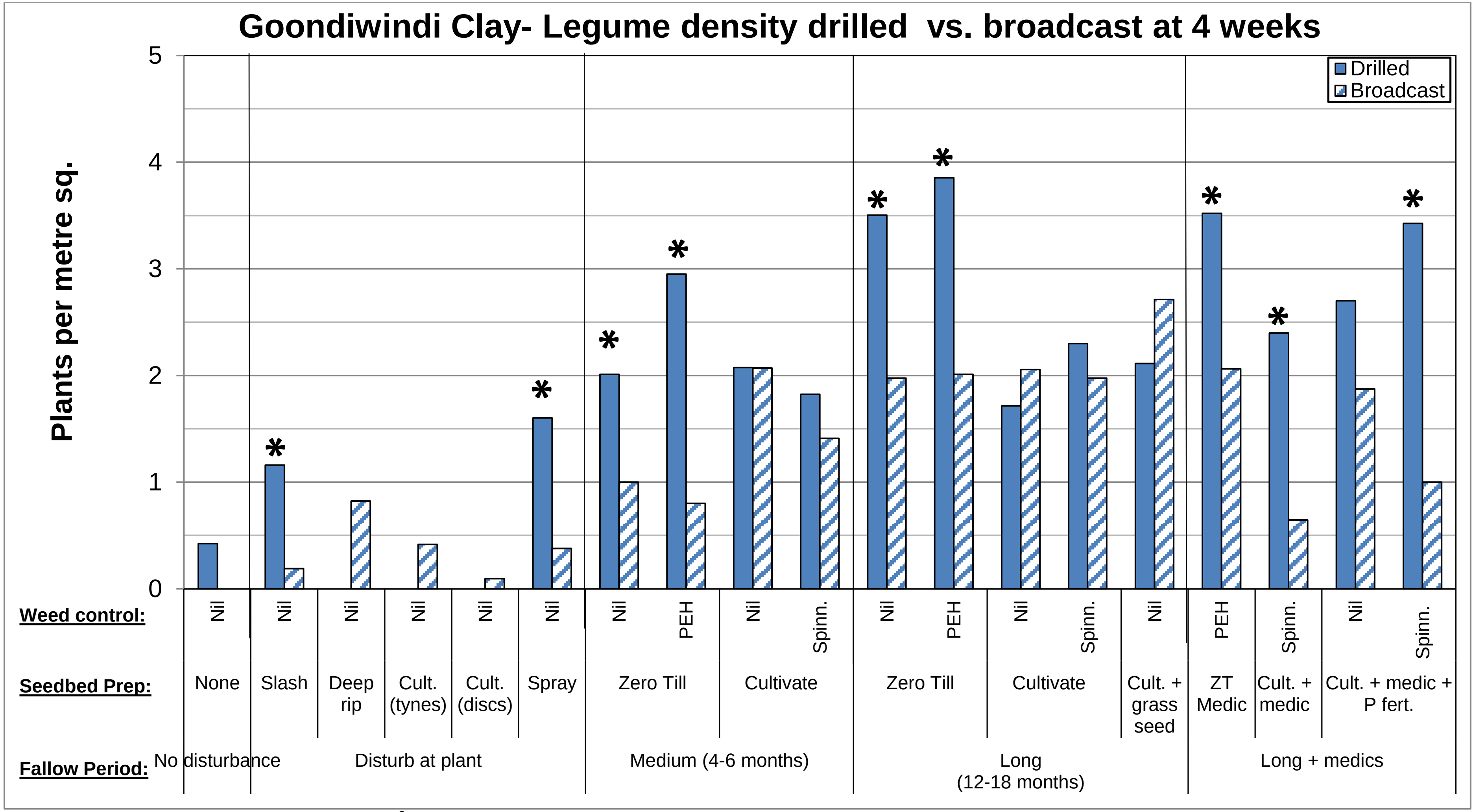

Fig. 39: Legume plant density (plants/m^2) at the Goondiwindi clay soil legume establishment site for drill and broadcast sowing methods, 8 weeks after germinating rain. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

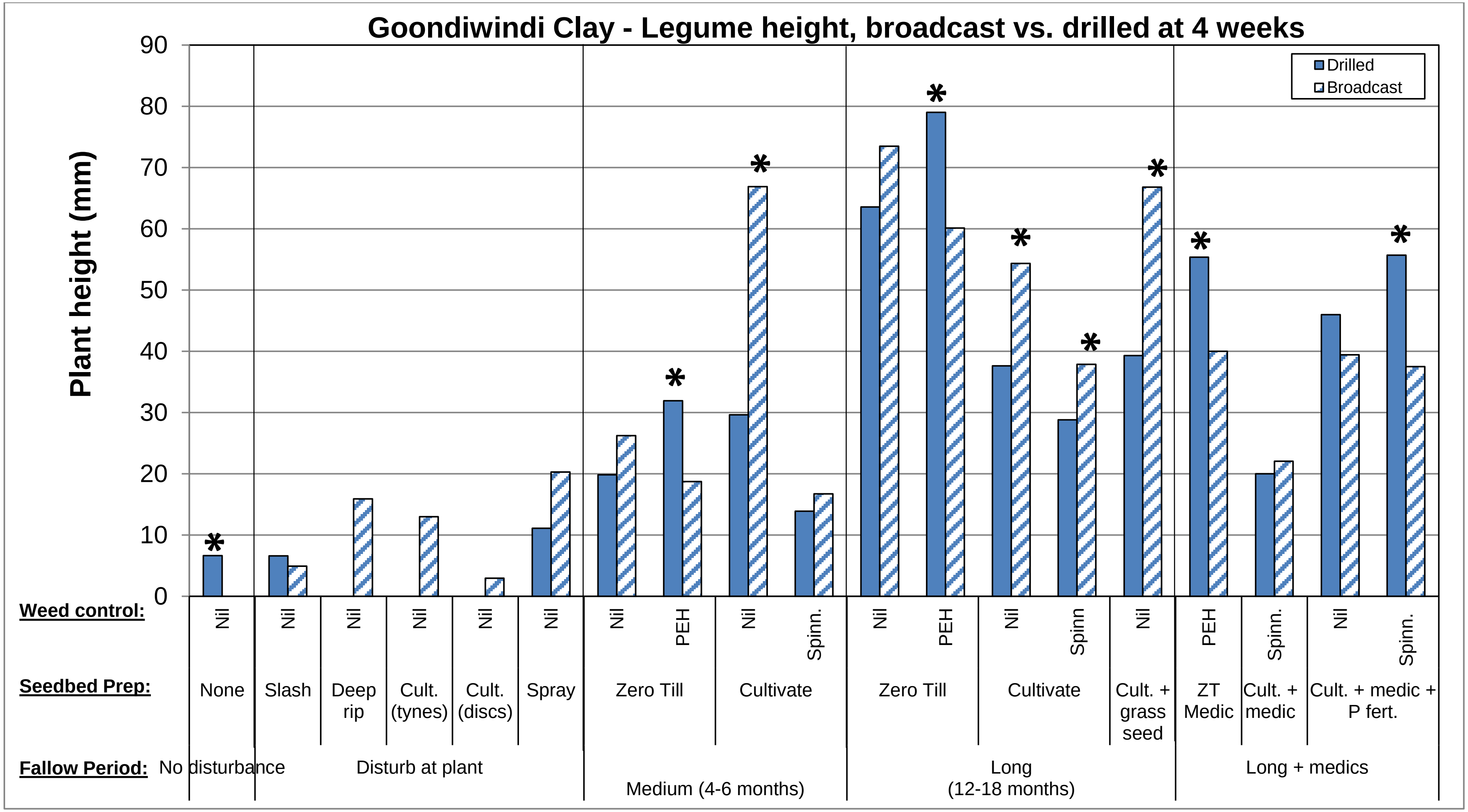

Fig. 40: Legume plant height (mm) at the Goondiwindi clay soil legume establishment site for broadcast and drill sowing methods, 4 weeks after germinating rains. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

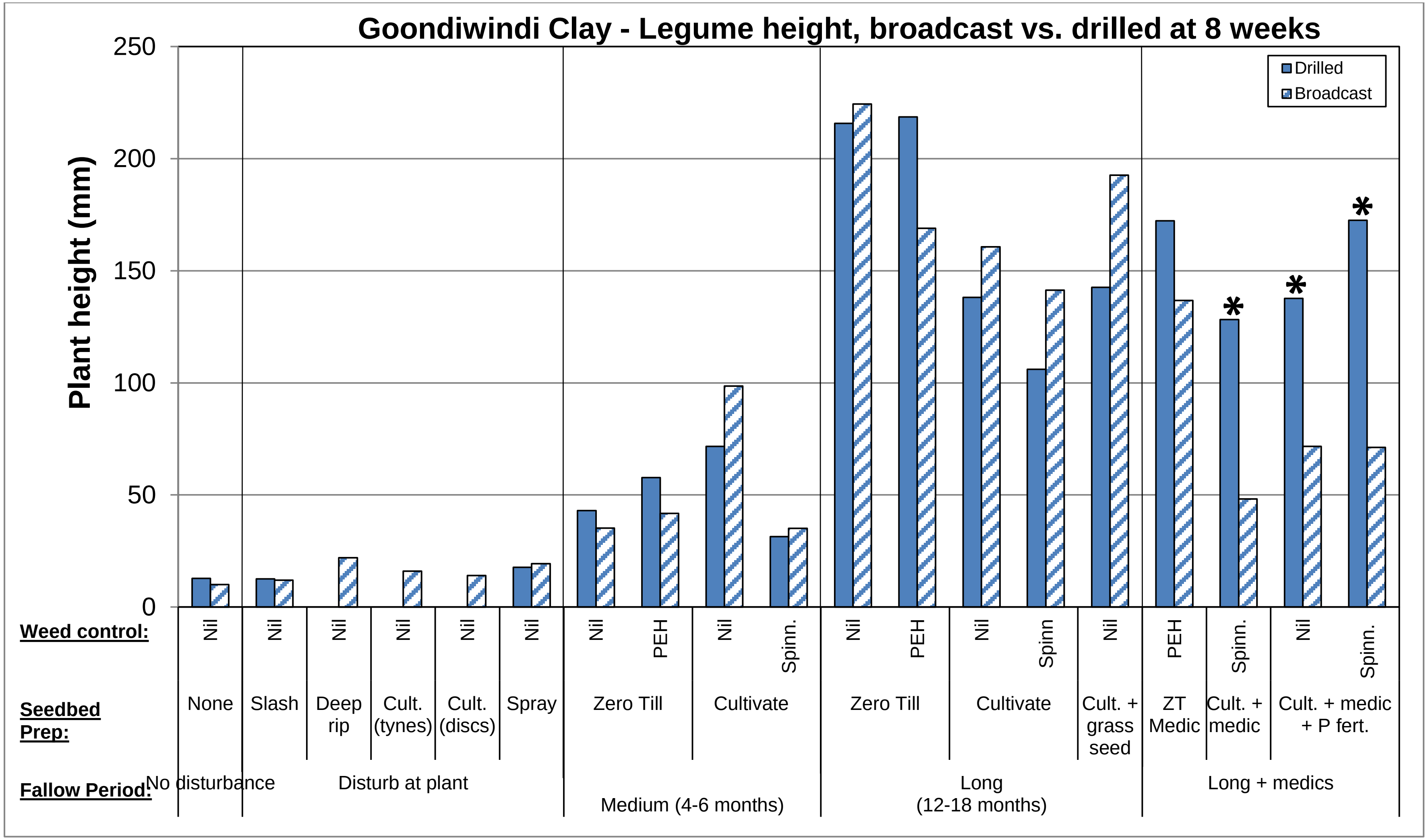

Fig. 41: Legume plant height (mm) at the Goondiwindi clay soil legume establishment site for broadcast and drill sowing methods, 8 weeks after germinating rains. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.2.2 Goondiwindi loam site

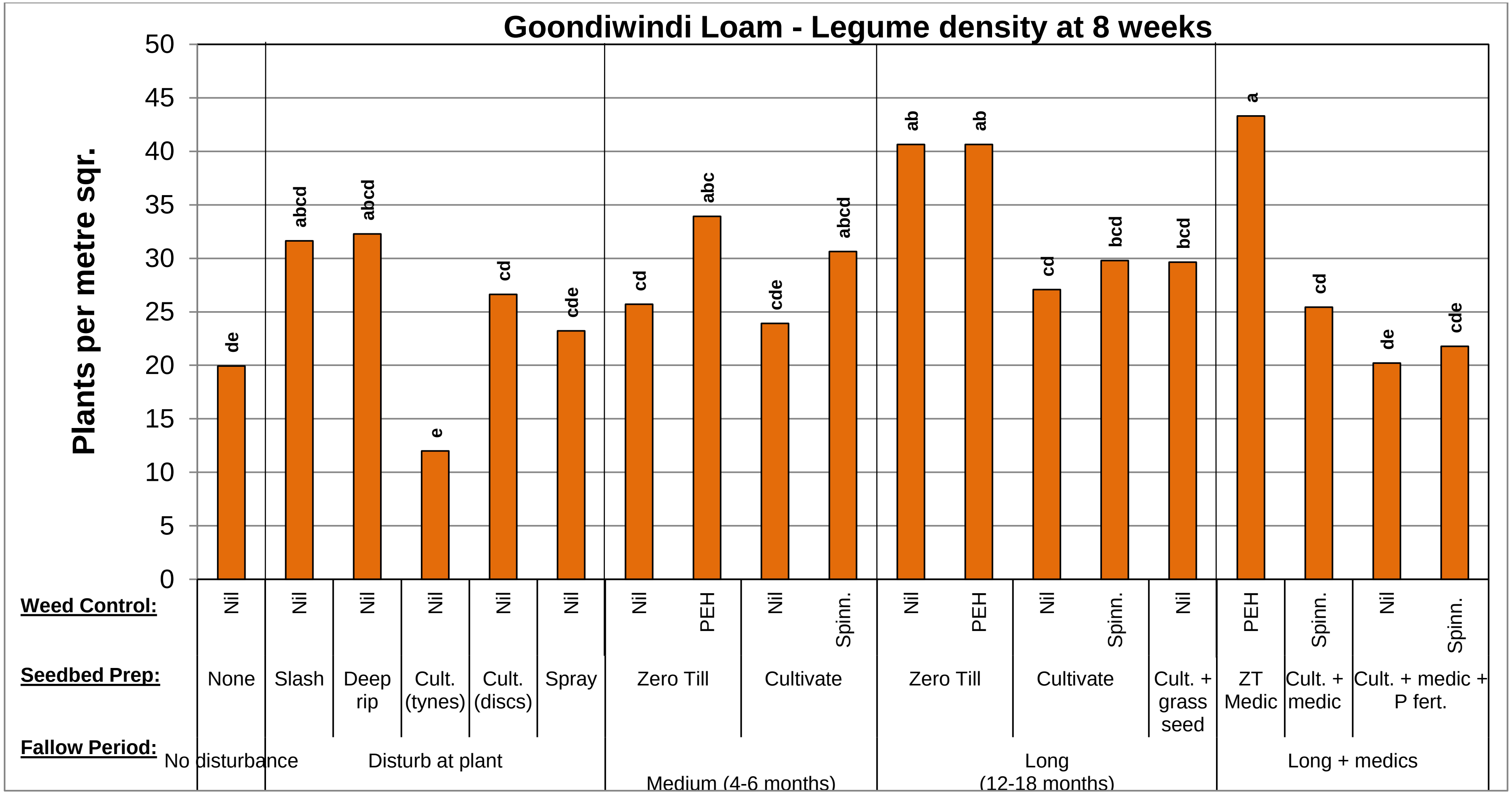

Fig. 42: Legume plant density (plants/m^2) at the Goondiwindi loam soil legume establishment site, 8 weeks after germinating rain. Significant effects were only recorded at the seedbed treatment level. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

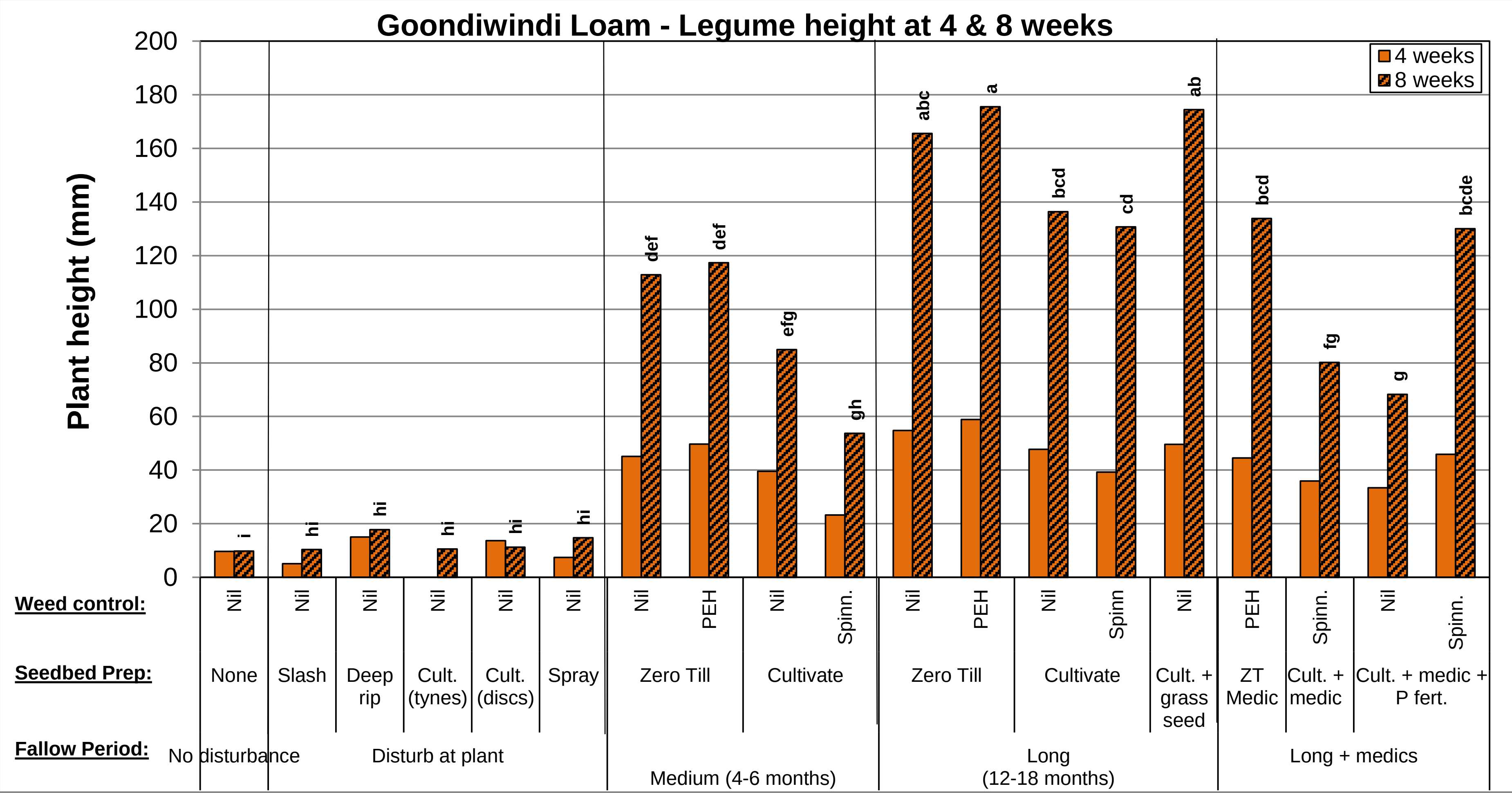

Fig. 43: Legume plant height (mm) at the Goondiwindi loam soil legume establishment site at 4 and 8 weeks after germinating rain. Significance shown for week 8 data (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

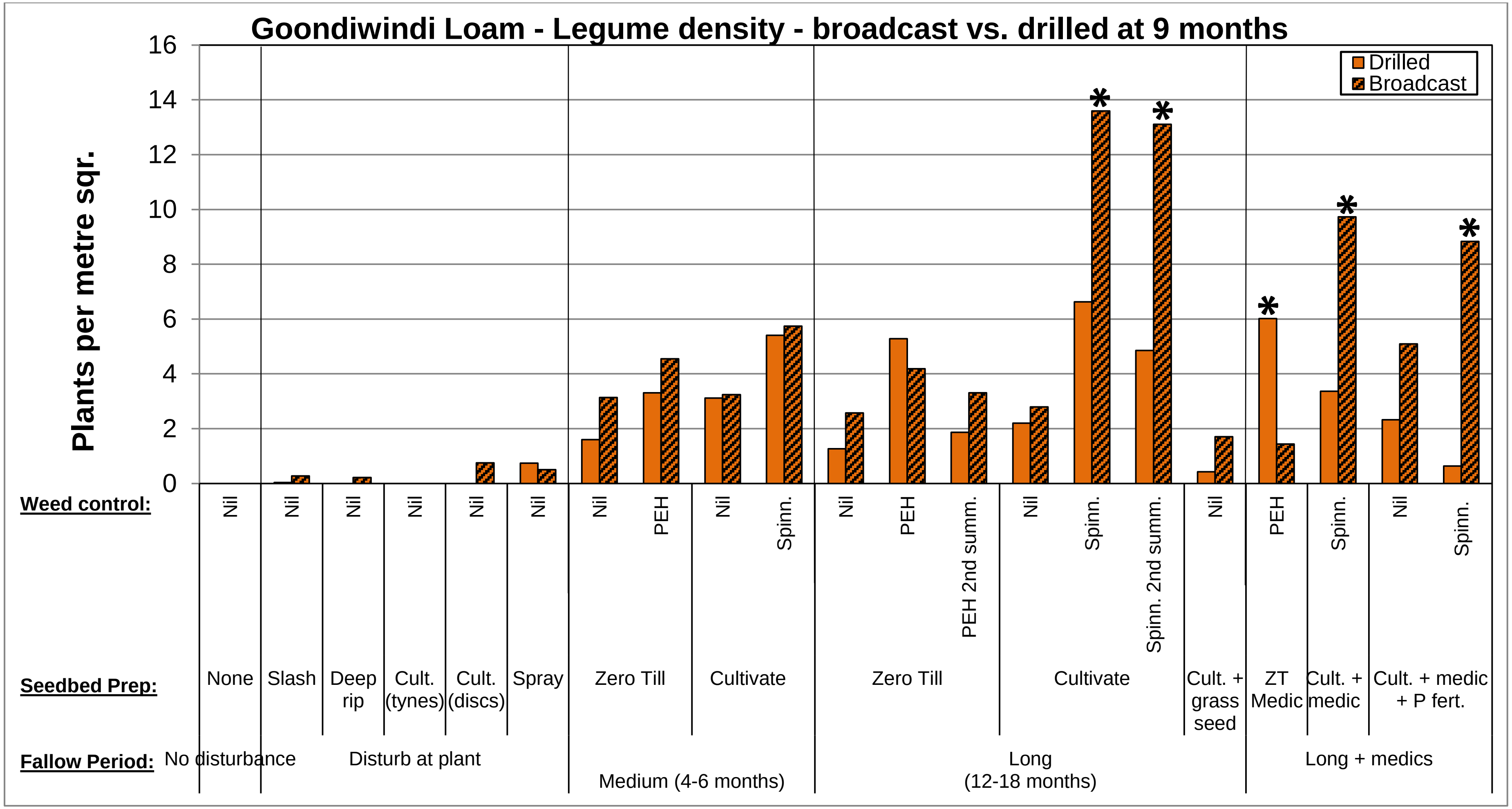

Fig. 44: Legume plant density (plants/m2) at the Goondiwindi loam soil legume establishment site for drill and broadcast sowing methods, 4 weeks after germinating rain. Asterisks denote instances in which a particular sowing method produced significantly higher plant numbers (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.3 Wandoan results

8.3.1 Wandoan clay site

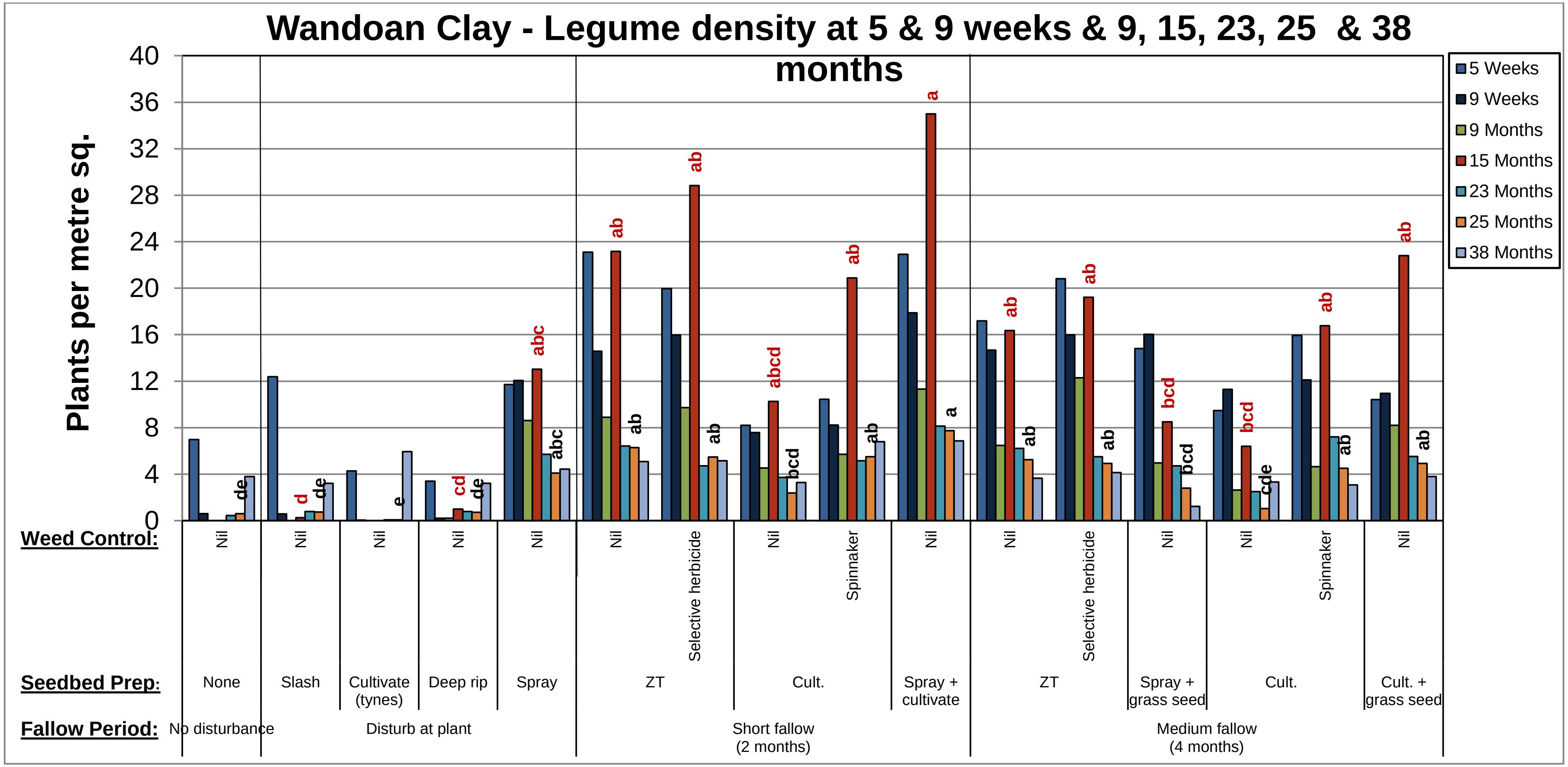

Fig. 45: Legume plant density (plants/m2) at the Wandoan clay soil legume establishment site 5 and 9 weeks and 9, 15, 23, 25 and 38 months after germinating rain. (PEH: post-emergent herbicide, using Verdict for grass control and Basagran for broad-leaf weeds; Spinn.: Spinnaker residual herbicide).

8.3.2 Wandoan loam site

The Wandoan loam establishment site was sown in February 2013 with fine stem stylo (*Stylosanthes guinensis*) and Progardes desmanthus. The trial was however abandoned in the 2013/14 summer due to severe grazing damage by wildlife. Results recorded to 9 weeks are presented in the tables below.

Table 7: Fine-stem stylo seedling number and height 9 weeks after germinating rains for different establishment techniques on a brigalow clay soil near Wandoan.

Seedbed preparation	Seedbed treatment	Post plant weed control	Fine-stem stylo	
			Plant Number (plants/m²)	Height of tallest plant (mm)
No disturbance	Slash	Nil	15.57 bcde	17.4 g
	None	Nil	18.00 bcde	16.8 g
Disturb at plant	Deep rip	Nil	4.43 e	33.1 fg
	Spray	Nil	21.14 abcd	51.3 ef
	Cultivate (tynes)	Nil	12.00 cde	18.3 g
Short fallow (2 months)	Spray	Selective herbicide	7.71 de	57.9 def
		Nil	17.43 bcde	61.4 cde
	Cultivate	Spinnaker	33.71 a	86.1 bc
		Nil	27.57 ab	108.6 ab
	Spray + cultivate	Nil	21.43 abcd	72.7 cde
Medium fallow (4 months)	Spray	Selective herbicide	17.14 bcde	78.5 cd
		Nil	12.71 cde	68.1 cde
	Spray + grass seed	Nil	20.43 abcd	113.3 a
	Cultivate	Spinnaker	24.71 abc	109.8 ab
		Nil	25.00 abc	125.0 a
	Cultivate + grass seed	Nil	12.43 cde	48.8 ef

Drilling the seed resulted in higher plant populations and larger plants at the loamy site. On average across the treatments there is an extra 14 stylo plants/m^2 with tallest plants also 20mm taller from drilling compared to broadcasting seed. For desmanthus there was on average an extra 4.1 plant/m^2 from drilling compared to broadcasting seed, but no improvement in plant height.

Table 8: : Fine-stem stylo seedling number and height 9 weeks after germinating rains for different sowing methods (broadcast vs. drill) on a brigalow clay soil near Wandoan.

Seedbed preparation	Seedbed treatment	Post plant weed control	Fine-stem stylo			
			Plant Number (plants/m^2)		Height of tallest plant(mm)	
			Broadcast	Drilled	Broadcast	Drilled
No disturbance	Slash	Nil	7.71	23.43	12.62	22.14
	None	Nil	2.57	33.43	12.5	21.07
Disturb at plant	Deep rip	Nil	4.43		33.13	
	Spray	Nil	8.86	33.43	43.75	58.93
	Cultivate (tynes)	Nil	12		18.25	
Short fallow (2 months)	Spray	Selective herbicide	2.57	12.86	50.62	65.18
		Nil	7.14	27.71	52	70.71
	Cultivate	Spinnaker	32.57	34.86	81.43	90.71
		Nil	28.57	26.57	108.21	108.93
	Spray + cultivate	Nil	12.29	30.57	73.92	71.43
Medium fallow (4 months)	Spray	Selective herbicide	3.71	30.57	51.33	105.71
		Nil	9.43	16	49.17	87.08
	Spray + grass seed	Nil	20.86	20	116.43	110.12
	Cultivate	Spinnaker	24.57	24.86	110.36	109.29
		Nil	18	32	116.43	133.57
	Cult. + grass seed	Nil	2	22.86	31.25	66.31

The table above provides more detail about the impact of drilling seed compared to broad casting on the loamy soil for fine-stem stylo. On average across treatments drilling produced an extra 14 plants/m2 and was strongly statistically significant (<0.05). The largest response to drilling was on treatments that had not been cultivated or only weakly cultivated (e.g. sprayed fallows). The smallest or no response to drilling was from cultivated fallow treatments. The response to drilling is most likely due to better soil seed contact but statistically the difference was not strongly significant (significant at <0.10) between seedbed treatments.