The rise and fall of Siratro (*Macroptilium atropurpureum*) − what went wrong and some implications for legume breeding, evaluation and management

RICHARD M. JONES

Keywords: Long-term persistence, soil seed banks, seedling survival, stolon density, grazing pressure, Australia.

Abstract

Siratro (*Macroptilium atropurpureum*) cv. Siratro was one of the first tropical legumes released for commercial use in the 1960s. It initially showed great promise in experiments and commercial sowings. Early research showed it was unproductive under heavy grazing, but after some 15 years there was increasing concern about its persistence, even under light to moderate grazing pressure. Commercial usage subsequently declined markedly although siratro, usually as cv. Aztec, is still sown to a very limited extent. This paper examines some reasons for this decline and then discusses some implications for research into improving tropical pastures through the use of legumes. In general, early pasture research, such as that on Siratro, failed to recognize that original plants of herbaceous legumes had a limited life span and that, for long-term persistence, new plants had to develop through vegetative or sexual reproduction. However, many studies over a 20-year time span showed that, although Siratro could form new plants, in most cases these replacements were insufficient to maintain an adequate plant density in the long term. Data on stolon density, plant longevity, soil seed banks and seedling survival, under different rainfall regimes and stocking rates, are presented to illustrate this. The major limitation was that soil seed banks were generally inadequate to ensure persistence, especially through a period of drier years, when there would be little or no seed set and possibly the death of all seedlings, which emerged from isolated falls of rain. Autumn spelling of pastures to enhance seed set improved persistence, but not reliably enough to be of widespread practical use. The major implication is that evaluation studies failed to adequately recognize the need for introduced legumes to form new plants after the original ones died. This has implications for future experiments, in terms of: duration; the management regime(s) imposed; the measurements or observations taken; and the need for a more ecological approach in evaluation.

Resumen

Siratro (*Macroptilium atropurpureum*) cv. Siratro fue una de las primeras leguminosas forrajeras tropicales liberadas para uso comercial en Australia en la década de 1960. Inicialmente se mostró muy promisorio tanto a nivel de estación experimental como en siembras comerciales. Mientras al comienzo las investigaciones mostraron que pastoreo intensivo tuvo efecto negativo en la productividad de la leguminosa, 15 años después habían incrementado las dudas sobre su persistencia en condiciones de pastoreo aún con cargas animales ligeras a moderadas. Como consecuencia, el uso comercial de Siratro ha venido declinando en forma marcada, aunque en áreas muy reducidas todavía se encuentran algunas siembras del cv. Aztec. En este documento se analizan algunas de las razones de este descenso en el uso de Siratro y sus implicaciones en las investigaciones sobre mejoramiento de pasturas mediante la introducción de leguminosas. En general, la investigación inicial en pasturas tropicales, tal como es el caso de Siratro, no tuvo en cuenta que las plantas originales de leguminosas herbáceas tienen un ciclo de vida reducido y que para garantizar la persistencia de una población es necesario que se desarrollen nuevas plantas mediante reproducción vegetativa o a partir de semillas. En numerosos estudios realizados durante un lapso de 20 años se demostró que, aunque Siratro forma nuevas

Correspondence: R.M. Jones, 20 Fairholme St, Kenmore, Queensland 4069, Australia.
Email: rmdjjones@bigpond.com

plántulas de reemplazo, en la mayoría de los casos éstas no son suficientes para mantener una adecuada densidad por un período prolongado de tiempo. Para ilustrar esto se presentan datos de estudios sobre densidad de estolones, longevidad de plantas, bancos de semilla en el suelo y sobrevivencia de plántulas en diferentes condiciones de pastoreo y clima. La principal limitante fue que los bancos de semillas en el suelo fueron generalmente inadecuados para asegurar la persistencia de la población, especialmente en años secos, cuando las plantas no alcanzaron a fructificar o solo muy poco, además del riesgo de muerte de todas las plántulas provenientes de semillas germinadas durante un evento de precipitación aislado. La interrupción del pastoreo en otoño para aumentar la producción de semillas en la pastura mejoró la persistencia de la leguminosa, pero no en una forma lo suficientemente confiable para un uso generalizado de esta práctica. La principal enseñanza es que los estudios de evaluación no reconocieron en forma adecuada que las leguminosas en una pastura tienen que formar plantas nuevas para reemplazar las plantas originales después de muertas. Esto tiene implicaciones para los futuros trabajos experimentales, en términos de duración de los experimentos, sistemas de manejo, mediciones y observaciones que se deben hacer, y la necesidad de un mayor enfoque ecológico en la evaluación.

Introduction

Cultivar Siratro was bred from 2 introductions of *Macroptilium atropurpureum*; a description of the breeding program can be found in Hutton (1962). Siratro was one of the first legumes released for use in sown tropical pastures in Australia. As this species was new to cultivation, nothing was known about the agronomy, ecology or persistence of Siratro as a pasture legume, when it was released in 1960.

It was soon found that Siratro was relatively easy to establish and grew on a wide range of soil types (Jones and Jones 1978). Although it was affected by some pests and diseases, the main limitation, prior to about 1980, was that, in higher rainfall areas receiving in excess of 1,400 mm/yr, it was susceptible to foliar blight caused by *Rhizoctonia solani*. However, it was later affected by rust caused by the fungus *Uromyces appendiculatus*. This led to the release of the rust-resistant cv. Aztec, which is otherwise genetically similar to cv. Siratro (Bray and Woodroffe 1995). However, almost all the detailed studies described later have been done on cv. Siratro. Cutting trials in the 1960s showed that yield was depressed by close and frequent cutting (Jones 1974a; 1974b) and this depression in yield was soon noticed at high stocking rates on grazed pastures in the early 1970s (Jones and Jones 2003). However, if moderately or lightly grazed, Siratro showed great promise. It sometimes comprised about 30% of pasture yield at the end of the growing season, increased soil nitrogen levels plus the N% of the associated grass, and supported good animal production (Mannetje 1967; Bisset and Marlowe 1974; Mannetje and Jones 1990; RJ Jones 2003; Jones and Jones 2003; Tothill et al. 2008a, 2008b).

Thus, it appeared to have great potential and was well accepted by farmers and graziers; so a special issue of *Tropical Grasslands* in 1977 (Vol. 11, No. 1), restricted to papers on Siratro, recognized the retirement of Dr Hutton.

However, in the late 1970s, doubts began to surface about the long-term persistence of Siratro in commercial sowings; so QDPI (Queensland Department of Primary Industries) organized a symposium in 1982 to gather data on experiences with Siratro persistence. Divergent views were expressed at the symposium (Brown 1983), with most concerns being raised by QDPI staff, based mainly on experience with commercial sowings. Contributions from CSIRO (Commonwealth Scientific and Industrial Research Organisation) staff, primarily based on results from a large grazing trial at Samford (1,000 mm annual rainfall) and 2 experiments at Narayen (720 mm), were more positive, although they clearly recognized that Siratro was not suited to heavy grazing pressure. Siratro had persisted for 5 years in one of these trials (Tothill et al. 2008a) and for about 10 years in the other 2 (Mannetje and Jones 1990; Jones and Jones 2003); so this positive response was to be expected. However, persistence subsequently declined in all trials and, by the time the trials were terminated after 15−20 years, Siratro was a minor component. Thus, the serious problems with long-term persistence of Siratro reported in commercial pastures eventually occurred in lightly grazed experimental pastures. Despite a marked decline in its popularity with primary producers, about 20 t of siratro seed (presumably both cvv. Siratro and Aztec) were produced annually in the mid-1990s (Smith 1996). Siratro is still used to a limited extent in both long-term pastures and short-term leys, usually as part of a mixture of legume species (e.g. Clarke 2008; McCamley 2010).

This paper reviews the knowledge of Siratro persistence to give some reasons for the persistence problem and then looks at some wider implications.

Persistence of Siratro

With the early enthusiasm about Siratro and other herbaceous legumes, one basic principle was largely overlooked – herbaceous perennial plants do not persist forever. To maintain a legume of this type in a pasture in the long term, it must form new plants, either from stolons or rhizomes or from seed. Fortunately, some related measurements of Siratro persistence were made in several grazing trials. Almost all of these trials were carried out with fixed stocking rates, usually with continuous grazing.

Life span of individual plants

Siratro plants often have a half-life (time for half the population to die) of about 1.5–3 years (Gutteridge 1985; Jones and Mannetje 1986; Jones and Bunch 1988a; Jones et al. 1993), although this obviously varies with management, site and rainfall. As a typical Siratro sowing rate of 3 kg/ha could equate to 25 seeds being sown per m^2, 10 or more plants could establish per m^2. After 2 years there could still be more than 5 plants per m^2 and, as these plants are large, the loss of density might not be reflected in reduced dry matter yield. This could even apply after 4 years with a density of over 2.5 plants per m^2.

There are data from 4 sites on the effect of stocking rate on the half-life of original plants. At Samford (Jones and Bunch 1988a) and in Thailand (Gutteridge 1985), a higher grazing pressure reduced plant half-life, while in the 2 experiments at Narayen, there was little effect (Jones and Mannetje 1986; Jones et al. 1993). This difference between Samford and Narayen could be partly due to the wider range of stocking rates imposed at the wetter Samford site (1,000 mm rainfall compared with 700 mm), and to the overall lower grazing pressures (weight of animals per weight of herbage) during active summer growth periods at Narayen. Interestingly, in one experiment at Narayen, low soil phosphorus status also had little effect on plant longevity (Jones et al. 1993).

Thus, with time Siratro density must obviously decline to the point where yield is negligible – unless new plants establish. The following sections look at recruitment from both stolons and seed, and consider how this is affected by grazing pressure and climate.

New plants from stolons

Formation of new roots from stolons was mentioned in the initial description of Siratro (Hutton 1962). However, while small roots can develop from thin soft stolons on the soil surface, these do not persist. Under some situations, which appear to be restricted to sites receiving in excess of 1,000 mm rainfall and under light stocking (Bisset and Marlowe 1974; Walker 1981; Jones and Bunch 1988a), Siratro can form much firmer woodier stolons, which are often just under the soil surface. Growing points and roots can develop on these stolons. At a moderate stocking rate of 1.7 heifers/ha at Samford, the total length of these stolons was about 1 m per m^2 for about 10 years, but no stolons remained after 16 years. There were more stolons in a pasture lightly stocked at 1.1 heifers/ha, but none under heavy grazing. Further details about stolon length and size, and on the density and size of rooted points, are given by Jones and Bunch (1988a). Stolons were never observed at the drier Narayen site.

Overall, it seems that stolons are not the major pathway for Siratro persistence.

New plants from seed

Data from Samford (Jones and Bunch 1988a) and Narayen (Jones and Mannetje 1986; Jones et al. 1993) show that new plants can develop from soil seed reserves. In a moderately grazed pasture (1.7 heifers/ha) at Samford, seedling replacement maintained good densities of 6–13 plants/m^2 for 7 years after the density of the original plants had fallen below 1 plant/m^2 (Jones and Bunch 1988a; 1988b). Long-term persistence seemed assured. In contrast, density declined markedly under a higher grazing pressure, as crowns had a shorter life span and there were progressively fewer new plants. However, during the next 5 years, replacement in the moderately grazed pasture did not match plant death, and Siratro density fell to 1 plant/m^2. In part, this was due to less favorable rainfall conditions for seed set and to increased grazing pressure in generally dryer years. Siratro rust did not seem to be a major factor, but could have exacerbated the problem of poor persistence; it can reduce leaf and seed yields, but its biggest impact is in monospecific swards or pastures with a high Siratro component (RJ Jones 1982). Other unknown factors could also be involved.

Similarly, in 2 experiments at Narayen, although there was certainly some successful recruitment from seedlings, long-term plant density was not maintained (Jones and Mannetje 1986; Jones et al. 1993).

In summary, while there may be some instances where plant density can be adequately maintained after the original plants die out, in many or most instances this does not happen. This decline in successful recruitment must be largely related to fewer seedlings, thus to the size of the soil seed bank, which in turn relates to the amount of seed set.

Seed set and soil seed banks

Measurements of seed reserves in the soil have been made in medium- to long-term trials at Samford (Jones 1979; Jones et al. 1980; Jones and Bunch 1998b) and Narayen (Mannetje and Jones 1986; Mannetje and Jones 1990; Mannetje and Butler 1991; Jones et al. 1993, 2000), and in spot measurements in some other trials (Tothill and Jones 1977). In summary, seed reserves rarely exceeded 500/m^2 and were usually about 200 or below, even in pastures with a good Siratro content.

Poorer or overgrazed Siratro pastures have much lower or negligible seed levels. In the heavily grazed pasture at Samford, sown in 1968, no Siratro flowers or pods were recorded after 1972, whereas the moderately grazed pasture usually had above 20 flowers or pods/m^2 up to 1982. Not surprisingly, in 1983/85 there were 167 seeds/m^2 in the moderately grazed pasture but only 15 seeds/m^2 in the heavily grazed pasture (Jones and Bunch 1988b). Soil seed numbers were usually significantly reduced by higher stocking rates at Narayen (Jones and Mannetje 1986; Mannetje and Jones 1990; Jones et al. 1993) and were lower at a higher stocking rate in Thailand (Gutteridge 1985).

Although some slight moisture stress can aid initiation of flowering in Siratro, it appears that in dryer areas, such as Narayen, dry conditions in autumn, when seed set occurs, are a major factor contributing to low soil seed numbers. Under dry conditions, aerial stems on Siratro plants can even die back towards the crown and, if stems die, no flowering or seeding occurs. Paradoxically, there was a complete failure of seed set in one year at Samford with sustained wet conditions in autumn (author's unpublished data). There were many pods, but no hard seeds; all seeds were soft or rotten, or prematurely germinated in the pods.

The number of legume seeds measured in good Siratro pastures is about 5–25% of that found in good pastures of other persistent legumes in southeast Queensland, such as Wynn cassia (*Chamaecrista rotundifolia*) (Jones 1995; Jones et al. 2000), shrubby stylo (*Stylosanthes scabra*) (Jones et al. 1993; 2000), Bargoo joint vetch (*Aeschynomene falcata*) (Jones et al. 2000), fine stem stylo (*Stylosanthes hippocampoides*) (Orr 2008) and white clover (*Trifolium repens*) (Jones 1982; 1984). In a 1993 paper comparing the persistence of Wynn cassia, Verano stylo (*Stylosanthes hamata*), shrubby stylo and Siratro, there was a suggestion that, for any pasture legume, 'within reasonable ranges, there is a "trade off" between longevity and seed set. Perhaps a key weakness of Siratro is that the seed banks are outside this reasonable range and too low to ensure recruitment, even at moderate stocking rates' (McIvor et al. 1993).

Seedling establishment

Most seed set in pastures cannot subsequently be accounted for. In one experiment at Samford, hand-collected Siratro seed was broadcast into 2 sites in closely grazed Siratro-free pastures ideal for seedling emergence. Over the subsequent 6 years, only 21% of the seed was accounted for as seedlings and a further 15% as soil seed (Jones 1981). Similar low recoveries have been recorded with other species in similar experiments. Furthermore, most emerging seedlings, and in many instances all seedlings, will die. This is usually attributed to moisture stress, when the small seedling root system is competing with the established pasture for water (Cook and Ratcliff 1985; Jones and Mannetje 1986; Jones and Bunch 1988b; Mannetje and Jones 1990). Competition from associated grasses can greatly reduce Siratro density when compared with monospecific Siratro swards on clay soils (Keating and Mott 1987; Peake et al. 1990), but reduced half-life, lower seed set and increased seedling mortality could all be involved. Another source of seedling loss in high-yielding and lightly grazed pastures is that there can be almost complete death of emerging Siratro seedlings due to competition for light (Agishi 1974; Jones and Bunch 1988b).

Effects of defoliation

Because of the growth habit of Siratro, with its long twining aerial stems with long internodes, heavy grazing greatly reduces the number of growing points (Clements 1989b) and therefore forage yield. However, as outlined above, the reduction in Siratro persistence under heavy grazing must operate through the effects on plant half-life, seed set, soil seed banks and seedling recruitment, or, less importantly, on stolon development and persistence.

There are not enough data to make any specific comments about how rotational grazing systems could affect Siratro persistence. At Samford, results from a 4-year experiment suggested that Siratro yield and persistence were slightly better in a rotation with long rest periods, but that this would be obtained only at stocking rates where the pastures were probably overgrazed in terms of animal production (Jones 1979). At Narayen, there were only minor differences in Siratro yield and persistence when continuous grazing was compared with a 4 weeks on:4 weeks off rotation for 4 years (Mannetje and Jones 1990). There is no information about the effect of cell grazing on Siratro persistence. In any rotational system with lengthy periods of stay in each paddock, there is the possibility that the timing of grazing in relation to Siratro flowering and seeding may have a different effect on seed set in different paddocks.

Effects of climate

Siratro has a lower ability to set seed under dry conditions than other herbaceous legumes such as shrubby stylo, Wynn cassia and Bargoo joint vetch. This is illustrated by data from an experiment at Narayen (Jones et al. 2003), supported by data from a wider range of experiments. This is in part due to the growth habit of Siratro, where flowers are borne towards the ends of long aerial stems, and partly from its lower tolerance of moisture stress compared with shrubby stylo. In an experiment at Narayen, where soil seed reserves of Siratro were measured annually, the progressive annual levels were 42, 18, 285, 109, 62, 32, 13 and 11 seeds/m^2, averaged over all treatments (Jones et al. 1993). Clearly seed reserves increased in only one year and the impact of this one year's seeding on reserves lasted for only 3 years. Tothill et al. (2009) also commented on the effects of a series of years with below average rainfall on Siratro seeding and persistence. In a similar environment to that at Narayen, variation in rainfall had a greater effect on the population dynamics of fine stem stylo than stocking rate (Orr 2008).

Frosting is a feature of the climate in subtropical Queensland. In most years, Siratro flowering and seeding have ended before the onset of severe frosting, so frost is unlikely to have a major effect on size of soil seed banks. Limited evidence also suggests that, in terms of crown survival, Siratro is one of the more frost-tolerant tropical legumes (Jones 1969).

Putting the pieces together

As a result of the studies described above, we have a reasonable, but certainly not perfect, understanding of how the different components of Siratro persistence – plant survival, stolons, seed set, soil seed banks and seedling survival – are affected by grazing pressure and rainfall.

How did this understanding of Siratro persistence develop?

This understanding did not develop as a result of measurements made to validate a conceptual model. Rather, as described below, the understanding and model gradually evolved as more measurements were made. The first demographic measurements followed casual observations in 1969 of Siratro seedlings in a pasture established in 1966 (Rees et al. 1976) and from sheer curiosity about their survival. These very limited measurements led to more detailed work on seedling emergence and survival under contrasting stocking rates in an existing experiment at Samford, starting in 1970 (Jones and Bunch 1988a). It soon became obvious that, to understand how these measurements of seedlings fitted into the overall picture, there was a need to measure plant survival, stolons where present, and soil seed banks. These are the key measurements in simple conceptual models of persistence (Jones and Mott 1980; Jones 1985; McIvor et al. 1993) and helped to partly explain the effects of stocking rates on persistence.

These interesting results from Samford then led to some demographic measurements being taken in the later years of 2 existing grazing experiments at the drier Narayen site (Tothill and Tessel 1982; Mannetje and Jones 1990) and to more comprehensive measurements in 2 new Narayen trials that started around 1980 (Jones and Mannetje 1986; Jones et al. 1993). The Narayen measurements gave valuable insights into the role of moisture stress in limiting seed set and seedling recruitment, regardless of stocking rate. It is questionable if this gradual understanding of the mechanisms of Siratro persistence could be achieved under the current research trend to shorter-term and goal-specific experiments.

Implications

Implications for Siratro management

The obvious implication from all studies on Siratro is that lighter grazing assists Siratro persistence through increasing seed set and, at times, longevity of crowns, as well as sometimes increasing stolon development. However, results from commercial experience and research indicated that this alone was not enough to reliably ensure persistence (Brown 1983). The next step was to examine the effects of resting in late summer and autumn on seed set in autumn, the main seeding period. Results have been equivocal. Resting can have a major impact on seed set; for example, in one year a 30- to 60-fold increase in seed set was recorded at Narayen with late season resting (Tessel 1983). However, in another study, although resting increased Siratro yield, there was no measureable effect on the soil seed bank (Jones and Jones 2003).

Most of the differences in seeding recorded in these studies could be attributed to differences in rainfall patterns and yield of Siratro. There have also been instances where light grazing or resting of commercial pastures, in conjunction with successive good rainfall years, substantially increased Siratro populations and yield (SJ Cook and CK McDonald personal communications). Other experiments examined the use of rough cultivation of established pastures to enhance Siratro seed germination and to aid seedling survival through reducing competition from established plants (Bishop et al. 1981; Jones and Jones 2003).

The findings from all the related studies are that both rough cultivation and late season resting, especially in years with good rainfall, can sometimes aid Siratro seed set, seedling recruitment and persistence (Hurford 1979; Jones 1979, 1988; Bishop et al. 1981; Tessel 1983; Jones and Jones 2003; Tothill et al. 2009). However, these practices are not sufficiently reliable to ensure confidence in the persistence of Siratro and hence widespread use in permanent pastures. Furthermore, there will always be some reluctance by many farmers or graziers to lightly graze good Siratro pastures in autumn, when grass quality is declining. This reluctance to graze lightly could even apply to the peak growth period in summer, although cattle usually prefer grass to Siratro during this period (Stobbs 1977).

Implications for further selection or breeding

Unfortunately, the objectives of the second breeding program on *Macroptilium atropurpureum* during the late 1960s and 1970s (Hutton and Beall 1977) were not related to enhancing the persistence mechanisms outlined above. However, following later characterization of 230 accessions of *M. atropurpureum*, a group of 45 lines was defined as having more branching and earlier flowering than Siratro (McDonald and Clements 2005). Seventeen of the 230 accessions, including some from this group, were compared for 5 years under farm grazing at 2 sites in southeast Queensland, but no single line maintained significantly higher densities than Siratro or Aztec at both sites (Bray et al. 2000).

If a clearly defined and important breeding target, which would obviously impact on plant survival and seed set, e.g. disease resistance in top growth or roots, can be identified, there is potential for breeding to assist legume persistence. A simple example is the improved persistence of *Medicago sativa* in southeast Queensland, produced by breeding for resistance to aphids and root diseases (Clements et al. 1984). Although Aztec, a rust-resistant cultivar of siratro, has been available for about 15 years, there is no feed-back that rust resistance is appreciably improving siratro persistence.

Disease or pest resistance apart, breeding for improved persistence in a legume, that persists in the long term through seedling recruitment, is very difficult – do you target longer crown life, more seed set, a higher level of hard seed or greater seedling vigor? The target has to be defined and then adequate variation found in plant collections. Furthermore, defining a target, such as higher seed set, is not enough. How much of an increase will you need in this attribute, before it will have an impact in commercial pastures? In addition, there is always the risk that selecting for an increase in one attribute may inadvertently lead to a decline in other desirable attributes of persistence, or even yield. Good advice on breeding for legume persistence has been presented elsewhere (Clements 1989a).

Implications for weediness

In some situations Siratro can be a weed, as it can climb over other plants and set considerable amounts of seed if not defoliated. The characteristics that imbue persistence are similar to those which contribute to weediness. This was not appreciated in the early research on tropical legumes, when Siratro was released, but the potential for weediness must now be considered in any introduction and evaluation program. Extreme conditions of weediness, either minimal or excessive, are relatively easily recognized. White clover, for example, can be a weed in lawns, but world-wide it has been a great asset for increasing animal production and soil fertility with minimal or negligible disadvantage as a weed. However, sometimes the boundary between desirable and undesirable persistence and spread is difficult to recognize and to relate to growth form. For example, glycine (*Neonotonia wightii*) and Siratro have somewhat similar growth habits, when grown with grass. Yet, in my experience in coastal southeast Queensland, glycine, with its much greater ability to climb, is a far more serious weed in open or disturbed forests.

Implications for evaluation

This is where the studies on Siratro persistence could have the greatest implications. Initial stages of evaluation of legumes for long-term pastures have often involved lightly defoliated trials lasting only 2–3 years and only yield has been measured. As a result of the factors outlined above, such trials can be potentially useless or at best misleading in assessing long-term persistence, especially if the legumes are grown in pure swards. Preferably, trials of this nature should be conducted under one or more defoliation treatments approximating commercial practice for at least 5 years. This is especially so if the site experiences wide variation in rainfall and, for example, can experience 2 or more consecutive years with well below average rainfall or infrequent periods of sustained heavy rainfall with potential for waterlogging. Longer trials will obviously involve more input of time and labor. However, the time and effort usually spent in cutting and measuring yield in screening trials can be reduced appreciably by using calibrated visual estimates of yield and composition. These are quite adequate to document the higher-yielding lines (Jones 2001). Very useful measurements of legume density, or at least legume frequency (Cameron et al. 1989; Jones 2001), could be made, even if only at the end of the trial.

Given the time-consuming nature of demographic measurements, such as survival of individual plants and soil seed reserves, it is pointless to make them in short-term assessments of a large number of lines. The important thing is to recognize the limitations of such trials and at least look for flowering, seed set, stolon/rhizome development, seedling recruitment and such like.

Management of evaluation trials should relate to the conditions in which the legumes are likely to be used. In commercial situations, farmers often stock according to average conditions, which means they are overstocked in below average rainfall years. They tend to focus more on the short-term forage needs of their stock than on the long-term survival of the pasture. Hence, evaluation methods need to reflect this. For example, a multi-site study in coastal Queensland evaluated legumes specifically for heavily grazed pastures (Cameron et al. 1989). The legumes were sown into cultivated strips in closely grazed grass swards. Management was controlled in the first year, to allow for legume establishment and seed set. However, in subsequent years, the experiments were just a small section in a pasture which, hopefully, was heavily grazed by the co-operating farmer. The emphasis was on persistence, which was easily measured by species frequency. The results in this experiment matched subsequent commercial experience with the same accessions. In contrast, the grazing or cutting regimes for legumes being evaluated for short-term ley pastures or cut-and-carry systems would be much more lenient.

There may be a case for specific demographic measurements to assist in understanding or extrapolation of the results of later-stage evaluation or management studies. For example, measurements of soil seed reserves of Siratro at the end of a 5-year study of rotational grazing aided prediction of the effects the treatments could have on Siratro persistence, if they had been continued for longer (Jones 1979). In longer-term grazing trials, perhaps with 1–3 accessions subjected to different grazing systems or stocking rates, demographic measurements may help to understand why species did or did not persist and how the results might be extrapolated to commercial conditions (Jones et al. 2000). They could lead to suggestions for improved management for persistence, based on seasonal changes in grazing pressure (Jones 1982, 1984; Orr 2008).

Thus, keeping demographic concepts in mind throughout the legume evaluation process may improve predictions of persistence. More comments about what demographic measurements to make, and why, when, and how to make them, can be found elsewhere (Jones and Mott 1980; Jones 1985; Jones and Carter 1989; Hay et al. 2000).

Implications for thinking

During the early years of "pasture improvement", I suggest we may have had a too simplistic view of what we were trying to do. In essence, we were trying to remove an existing plant community, or at least introduce a legume into it, to form a new and more productive community, which would be resilient over time. Perhaps we were too simplistic, thinking more like engineers rather than ecologists.

It was as if we were engineers erecting a new bridge to replace an existing bridge, which had load (animal production) limitations. All you had to do was to supply the seed and fertilizer (concrete and reinforcing), avoid gross mismanagement (exceeding the load limit) and behold the new bridge would be stronger (productive) than the old one, and last for decades. Our approach was somewhat mechanical rather than biological. Whereas concrete and steel reinforcing usually last for decades, regardless of external forces, herbaceous plants do not. Furthermore, they have widely varying tolerances of external forces such as rainfall, fire, frosting, weed invasion and, especially, grazing pressure and frequency.

Perhaps we should recognize that evaluation of pasture species is, by and large, not science. It is simply a measurement of one or more simple attributes (often yield is the only one), when a range of accessions is subjected to one or more ad hoc defoliation treatments. Even if the defoliation treatments and experimental duration are chosen to reflect particular farm management practices, this does not make evaluation into a science – albeit it is a worthwhile thing to do. Science in evaluation is where we are concerned with underlying processes and attempts to answer questions such as the following: What makes some plants more resistant to defoliation than others? Why does one species need more phosphorus than another? How does a species persist in a pasture after the original plants have died? Why does one species spread into adjacent plant communities and another does not?

Some final personal comments

(1) In the 1950s and 1960s, when Siratro was developed and initially evaluated, very little was known about the potential, for good or bad, of incorporating tropical legumes in grazed pastures. At that time, the focus was on identifying legumes with high DM production. In retrospect, the development of Siratro was a good but imperfect start, but now the question is: "Are we learning from past shortcomings and doing things better?"

(2) Perhaps one of the surprising features of Siratro is that, given its growth habit, it was so successful and well accepted by graziers and scientists for more than a decade, and is still used to a limited extent. One possible reason for this relates to the climate of Queensland, which incorporates a cool season, usually dry, of 6 months or more. During this time, there is little or no pasture growth, which restricts animal numbers. Given an average or good warm season rainfall, growth is rapid and there is often plenty of forage, so the overall grazing pressure during the growing season is reduced, obviously favoring Siratro.

(3) In view of its ability to improve soil nitrogen status and N concentration in associated grasses (Mannetje and Jones 1990), Siratro may still have a useful role as part of a legume mixture for improving these characteristics in both long-term and ley pastures (McCamley 2010).

(4) Many of the early evaluation experiments were conducted for only 2–3 years, and measured yield only under light defoliation treatments. Unfortunately, they did not continue for long enough, ignored plant attributes related to persistence, and bore little relationship to commercial conditions as defoliation levels were too lenient.

(5) Having a "good" growth habit – prostrate stems that form roots, growing points that are largely protected from grazing, and a capability to set seed under close grazing – does not guarantee that a legume will persist in the long term. Both *Lotononis bainesii* cv. Miles and *Vigna parkeri* cv. Shaw have these attributes. However, despite early promise, lotononis has not persisted in the long term and no seed has been commercially produced in Queensland for about 10 years. *Vigna parkeri*, on the other hand, was rejected in early cutting experiments in favor of taller-growing species such as *Desmodium intortum* and its value was recognized only when it was seen invading and spreading under grazing at old trial sites (Jones 1984; Cook and Jones 1987). It has persisted well, seed is commercially available, and it is well regarded in the very limited area to which it is adapted.

(6) After having an interest in legume persistence for more than 40 years, I have recently revisited some former experimental sites to observe which legumes are persisting, and have received reports from others who have done likewise. In all cases, I had some experience with the species concerned and had made demographic measurements on many of them. Before looking at or learning about the sites, I formulated views on what the levels of persistence would be. In most instances, these predictions were quite accurate, but occasionally I was completely wrong. The message is: no matter how much experience or knowledge you have – be warned – predicting legume persistence, or botanical change generally, is often somewhat risky. The fewer years of experience, and the lower the demographic understanding, the greater the risk.

References

Agishi EG. 1974. Regeneration of Siratro (*Macroptilium atropurpureum*) in grazed pastures. M.Sc. Thesis. University of Queensland, Brisbane, Australia.

Bishop HG; Walker B; Rutherford MY. 1981. Renovation of tropical legume-grass pastures in northern Australia. Proceedings of the XIV International Grassland Congress, Lexington, KY, USA, 1981. p. 555–558.

Bisset WJ; Marlowe GWC. 1974. Productivity and dynamics of two Siratro based pastures in the Burnett foothills of south-east Queensland. Tropical Grasslands 8:17–24.

Bray RA; Woodroffe TD. 1995. *Macroptilium atropurpureum* (DC) Urban (atro) cv. Aztec. Australian Journal of Experimental Agriculture 35:121.

Bray RA; Jones RM; McDonald CK. 2000. An evaluation of 19 lines of *Macroptilium atropurpureum* at two sites in south-eastern Queensland. Technical Memorandum No. 4. Division of Tropical Agriculture, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Melbourne, Australia.

Brown RF. 1983. Siratro in south-east Queensland. Conference and Workshop Series QC 83002. Queensland Department of Primary Industries, Brisbane, Australia.

Cameron DG; Jones RM; Wilson GPM; Bishop HG; Cook BG; Lee GR; Lowe KF. 1989. Legumes for heavy grazing in coastal subtropical Australia. Tropical Grasslands 23:153–161.

Clarke B. 2008. Mexican standoff with Aztec atro still used by some farmers. Agriculture Today, April 2008. New South Wales Department of Primary Industries, Sydney, Australia.

Clements RJ. 1989a. Developing persistent pasture legume cultivars for Australia. In: Marten GC; Matches AG; Barnes RF; Brougham RW; Clements RJ; Sheath GW, eds. Persistence of forage legumes. American Society of Agronomy, Madison, WI, USA. p. 505–521.

Clements RJ. 1989b. Rates of destruction of growing points of pasture legumes by grazing cattle. Proceedings of the XVI International Grassland Congress, Nice, 1989. p. 1027–1028.

Clements RJ; Turner JW; Irwin JAG; Langdon PW; Bray RA. 1984. Breeding disease resistant, aphid resistant lucerne for subtropical Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry 24:178–188.

Cook BG; Jones RM. 1987. Persistent new legumes for intensive grazing: I. Shaw creeping vigna. Queensland Agricultural Journal 113:89–91.

Cook SJ; Ratcliff D. 1985. Effect of fertilizer, root and shoot competition on the growth of Siratro (*Macroptilium atropurpureum*) and green panic (*Panicum maximum* var. *trichoglume*) seedlings in a native speargrass (*Heteropogon contortus*) sward. Australian Journal of Agricultural Research 36:233–245.

Gutteridge RC. 1985. Survival and regeneration of four legumes oversown into native pastures in northeast Thailand. Journal of Applied Ecology 22:885–894.

Hay MJM; Jones RM; Orr DM. 2000. Plant population dynamics in grasslands. In: Mannetje L't; Jones RM, eds. Field and laboratory methods for grassland and animal production. CAB International, Wallingford, UK. p. 123–149.

Hurford R. 1979. Deterioration and renovation of pastures at "Bungawatta". Tropical Grasslands 13:181–182.

Hutton EM. 1962. Siratro, a tropical pasture legume bred from *Phaseolus atropurpureus* D.C. Australian Journal of Experimental Agriculture and Animal Husbandry 2:117–125.

Hutton EM; Beall LB. 1977. Breeding of *Macroptilium atropurpureum*. Tropical Grasslands 11:15–31.

Jones RJ. 1974a. Effect of an associated grass, cutting interval and cutting height on yield and botanical composition of Siratro pastures in a sub-tropical environment. Australian Journal of Experimental Agriculture and Animal Husbandry 14:334–342.

Jones RJ. 1974b. The effect of previous cutting interval and of leaf area remaining after cutting on regrowth of *Macroptilium atropurureum* cv. Siratro. Australian Journal of Experimental Agriculture and Animal Husbandry 14:343–348.

Jones RJ. 1982. The effect of rust (*Uromyces appendiculatus*) on the yield and digestibility of *Macroptilium atropurpureum* cv. Siratro. Tropical Grasslands 16:130–135.

Jones RJ. 2003. Effects of sown grasses and stocking rates on pasture and animal production from legume-based pastures in the seasonally dry tropics. Tropical Grasslands 37:129–150.

Jones RJ; Jones RM. 1978. The ecology of Siratro based pastures. In: Wilson JR, ed. Plant relations in pastures. CSIRO (Commonwealth Scientific and Industrial Research Organisation), Melbourne, Australia. p. 353–367.

Jones RM. 1969. Mortality of some tropical grasses and legumes following frosting in the first winter after sowing. Tropical Grasslands 3:57–63.

Jones RM. 1979. Effect of stocking rate and grazing frequency on a Siratro (*Macroptilium atropurpurem*)/*Setaria anceps* cv. Nandi pasture. Australian Journal of Experimental Agriculture and Animal Husbandry 19:318–324.

Jones RM. 1981. Studies on the population dynamics of Siratro: The fate of Siratro seeds following oversowing into sub-tropical pastures. Tropical Grasslands 15:95–101.

Jones RM. 1982. White clover (*Trifolium repens*) in subtropical south-east Queensland. I. Some effects of site, season and management practices on the population dynamics of white clover. Tropical Grasslands 16:118–127.

Jones RM. 1984. White clover (*Trifolium repens*) in subtropical south-east Queensland. III. Increasing clover and animal production by use of lime and flexible stocking rates. Tropical Grasslands 18:186–194.

Jones RM. 1985. Persistencia de las especies forrajeras bajo pastoreo. In: Lascano C; Pizarro E, eds. Evaluación de pasturas con animales. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia. p. 167–200.

Jones RM. 1988. The effect of stocking rate on the population dynamics of siratro in siratro (*Macroptilium atropurpureum*)/setaria (*Setaria sphacelata*) pastures in south east Queensland. III. Effects of spelling on restoration of siratro in overgrazed pastures. Tropical Grasslands 22: 5–11.

Jones RM. 1995. Yield and population dynamics of *Chamaecrista rotundifolia* cv. Wynn in coastal south-eastern Queensland as affected by stocking rate and rainfall. Tropical Grasslands 29:65–73.

Jones RM. 2001. Evaluation of legumes and grasses in coastal south-east Queensland. Tropical Grasslands 35:85–95.

Jones RM; Mott JJ. 1980. Population dynamics in grazed pastures. Tropical Grasslands 14:218–224.

Jones RM; Jones RJ; Hutton EM. 1980. A method for advanced stage evaluation of pasture species: a case study with bred lines of *Macroptilium atropurpureum*. Australian Journal of Experimental Agriculture and Animal Husbandry 20:703–709.

Jones RM; Mannetje L't. 1986. A comparison of bred *Macroptilium atropurpureum* lines and cv. Siratro in subcoastal south-east Queensland with particular reference to legume persistence. Tropical Agronomy Technical Memorandum No. 47. Division of Tropical Crops and Pastures, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Melbourne, Australia.

Jones RM; Bunch GA. 1988a. The effect of stocking rate on the population dynamics of Siratro in Siratro (*Macroptilium atropurpureum*)-setaria (*Setaria sphacelata*) in south-east Queensland. I. Survival of plants and stolons. Australian Journal of Agricultural Research 39:209–219.

Jones RM; Bunch GA. 1988b. The effect of stocking rate on the population dynamics of Siratro in Siratro (*Macroptilium atropurpureum*)-setaria (*Setaria sphacelata*) pastures in south-east Queensland. II. Seed set, soil seed reserves, seedling recruitment and seedling survival. Australian Journal of Agricultural Research 39:221–234.

Jones RM; Carter ED. 1989. Demography of pasture legumes. In: Marten GC; Matches AG; Barnes RF; Brougham RW; Clements RJ; Sheath GW, eds. Persistence of forage legumes. American Society of Agronomy, Madison, WI, USA. p. 139–158.

Jones RM; Kerridge PC; McLean RW. 1993. Population dynamics of Siratro and Fitzroy stylo in south-east Queensland as affected by phosphorus, soil type, stocking rate and rainfall. Tropical Grasslands 27:65–74.

Jones RM; McDonald CK; Clements RJ; Bunch GA. 2000. Sown pastures in subcoastal south-eastern Queensland: Pasture composition, legume persistence and cattle liveweight gain over 10 years. Tropical Grasslands 34:21–37.

Jones RM; Jones RJ. 2003. Effect of stocking rate on animal gain, pasture yield and composition, and soil properties from setaria-nitrogen and setaria-legume pastures in coastal south-east Queensland. Tropical Grasslands 37:65–83.

Keating BA; Mott JJ. 1987. Growth and regeneration of summer-growing pasture legumes on a heavy clay soil in south-eastern Queensland. Australian Journal of Experimental Agriculture 27:633–641.

Mannetje L't. 1967. Pasture improvement in the Eskdale district of south-eastern Queensland. Tropical Grasslands 1:9–19.

Mannetje L't; Jones RM. 1990. Pasture and animal productivity of buffel grass with Siratro, lucerne or nitrogen fertiliser. Tropical Grasslands 24:269–281.

Mannetje L't; Butler KL. 1991. Studies on buffel grass pastures with Siratro, lucerne or nitrogen fertilizer. 1. Herbage production, botanical composition, legume plant dynamics and changes in soil fertility. Tropical Agronomy Technical Memorandum No. 67. Division of Tropical Crops and Pastures, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Melbourne, Australia.

McCamley B. 2010. Improved pastures target long term savings. Queensland Country Life Newspaper, Brisbane, Australia, 29 May 2010.

McDonald CK; Clements RJ. 2005. Variation within the species *Macroptilium atropurpureum* regarding adaptation to grazing. Proceedings of the XX International Grassland Congress, Dublin, Ireland, 2005. p. 344.

McIvor JG; Jones RM; Taylor JA. 1993. Tropical pasture establishment. 4. Population dynamics of sown species in developing pastures. Tropical Grasslands 27:302–313.

Orr DM. 2008. Grazing management influences the dynamics of populations of *Stylosanthes hippocampoides* (Oxley fine stem stylo). Tropical Grasslands 42:193–201.

Peake DCI; Myers RKJ; Henzell EF. 1990. Sown pasture production in relation to nitrogen fertilizer and rainfall in southern Queensland. Tropical Grasslands 24:291–298.

Rees MC; Jones RM; Roe R. 1976. Evaluation of pasture legumes and grasses grown in mixtures in south-east Queensland. Tropical Grasslands 10:65–78.

Smith P. 1996. Pastures for prosperity − Seeds forum. 6. What we want from the seed industry in the future – a merchant's viewpoint. Tropical Grasslands 30:88–89.

Stobbs TH. 1977. Seasonal changes in the preference by cattle for *Macroptilium atropurpureum* cv. Siratro. Tropical Grasslands 11:87–91.

Tessel J. 1983. Seedling ecology and population dynamics of Siratro (*Macroptilium atropurpureum*) under different grazing regimes in S.E. Queensland, Australia. Unpublished report, Agricultural University of Wageningen, Wageningen, The Netherlands.

Tothill JC; Jones RM. 1977. Stability of sown and oversown Siratro pastures. Tropical Grasslands 11:55–65.

Tothill JC; Tessel J. 1982. Pasture spelling and pasture stability. Annual Report 1981-82, Division of Tropical Crops and Pastures, CSIRO (Commonwealth Scientific and Industrial Research Organisation), Melbourne, Australia. p. 93–94.

Tothill JC; McDonald CK; McHarg GW; Hargreaves JNG. 2008a. Development options in *Heteropogon contortus* grasslands in south-east Queensland: Tree killing, legume oversowing and pasture replacement. 1. Pasture production and composition. Tropical Grasslands 42:129–151.

Tothill JC; McDonald CK; McHarg GW; Hargreaves JNG. 2008b. Development options in *Heteropogon contortus* grasslands in south-east Queensland: Tree killing, legume

oversowing and pasture replacement. 2. Animal production. Tropical Grasslands 42:152–169.
Tothill JC; McDonald CK; McHarg GW. 2009. Effects of wet season rotational grazing on pasture and animal production in buffel (*Cenchrus ciliaris*)-siratro (*Macroptilium atropurpureum*) pastures in south-east Queensland. Tropical Grasslands 43:162–170.
Walker B. 1981. Effects of stocking rate on perennial tropical legumes grass pastures. Ph.D. Thesis. University of Queensland, Brisbane, Australia.

(Received for publication 27 June 2013; accepted 26 August 2013)

Jones RM. 2014. The rise and fall of Siratro (*Macroptilium atropurpureum*) − what went wrong and some implications for legume breeding, evaluation and management. Tropical Grasslands – Forrajes Tropicales 2:154–164.
DOI: 10.17138/TGFT(2)154-164