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Tropical pasture establishment.
1. A systems perspective of establishment illustrated by legume oversowing in the subtropics

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Abstract

A systems schema of pasture establishment is presented to provide a generic framework for understanding and analysing establishment processes, problems and outcomes. The system represents the establishment continuum by 8 phases; the first 4 deal with seed supply phases and their influence on seed properties before sowing, the other 4 with post-sowing field establishment sequences which determine the capacity of the developing sown species to contribute future production or resource-maintenance benefits.

Key biological, environmental and management variables operating in each phase and likely to influence establishment outcomes are illustrated through a case study of low input, oversown shrubby stylo (*Stylosanthes scabra*), a particularly useful example in which a species with high levels of hardseededness is sown into a difficult establishment environment. Aspects highlighted, which in some instances include the presentation of predictive relationships, are: the variation in hardseededness of legume seeds from different geographical sources or production environments, which is shown to be closely related to seed moisture content; the possible modification of hardseededness through different methods of seed harvesting and processing or by deliberate, physical modification of seeds before sowing; post-sowing softening of hard seed in response to surface temperature thresholds, and the increases in potential speed of germination related to small falls of rain before a significant field germination event; a dominant influence of water availability on germination and early seedling establishment; a demonstrated relationship between seedling death rates and soil water deficits in the root zone which becomes more acute under conditions of high evaporative demand and where there is competition from other plants; and the impact of enforced juvenility of seedlings, caused by competition, in delaying reproduction and increasing plant deaths when moderate frosting occurs.

A probabilistic assessment of the risks associated with oversowing is derived from a series of experimental field sowings of shrubby stylo in the Queensland subtropics. This quantifies the quite low levels and high risks of establishment associated with low input methods, and the appreciable improvement and moderation of these, respectively, when competition from other plants is controlled and when the best seed treatments are used to reduce hardseededness. An economic analysis of a number of establishment scenarios also illustrates the considerable financial penalty incurred with low input oversowing methods when pastures develop slowly or there is an establishment failure and the pasture is resown.

Introduction

Successful establishment is vital for the effective introduction and use of improved pastures and other sown forages in livestock and cropping enterprises. Rapid and reliable establishment, achieved as inexpensively as possible, provides the best opportunity for enhanced production, resource-maintenance benefits and profits. Establishment failures are costly and may also impede

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the adoption of new forage, farming system or land restoration technologies.

Tropical pasture and forage crop statistics for northern Australia give a perspective to the importance of establishment outcomes. Up to 300 000 ha of pastures have been sown annually in the last decade, when seasons and livestock commodity prices have been favourable, partly to replace old pastures and partly to increase the total area developed. Some 5 M ha are now developed, but an estimated 20 M ha could potentially be developed using existing technology (Walker and Weston 1991). About 500 000 ha of tropical and temperate forage crops are also planted annually. These sown pastures and forage crops produce quality forages that support the production of beef and dairy products worth more that $600M annually. Tropical grasses and temperate legumes contribute additional benefits by restoring soil fertility in mixed cash cropping and livestock enterprises in the inland subtropics.

Pasture development and forage options, and the establishment methods commonly used, may both be generically categorised. Options include: sowing of various legumes, grasses or legume-grass mixtures in permanent or ley pastures; introduction of legumes into native pastures or into rundown sown grass pastures within which legumes either were not initially sown or have failed to persist; planting of browse legumes; introduction of grazing-tolerant grasses into destabilised or legume-augmented native pastures; restoration of preferred grasses in degraded native pastures; and annually sown forage crops. Establishment methods, generally in order of increasing inputs and costs and decreasing risk, include: surface sowing either without disturbance or with minimal disturbance from fire, heavy grazing, rough cultivation or herbicides (oversowing); sod-, slot- or band-seeding; sowing with a cover or pioneer crop (undersowing); and sowing alone into a fully cultivated seedbed.

Despite the complexity represented in the range of plant species used for forage, the various pasture development options available and the differences among establishment methods, this paper aims to provide a systems framework of establishment to highlight the principles involved in understanding and analysing establishment problems and outcomes. Firstly, the scope and main variables of the system are defined. Secondly, the establishment of shrubby stylo (*Stylosanthes scabra*) when oversown without soil disturbance is used as a case study to illustrate key phases and processes influencing establishment risks and outcomes. The case study is developed using some of our research findings and highlights the often complex interactions occurring among biological, environmental and management factors during establishment.

The pasture establishment system

System boundaries

Establishment may be defined biologically as: *the sequences of seed germination and seedling development that normally permit the persistence of the introduced species in the longer-term.* A definition more meaningful to producers would be: *the conversion of seed or other propagating material into production or resource-maintenance benefits.*

From a systems perspective, however, the definition of pasture establishment must logically also embrace the provision of seed supplies. Apart from the absolute requirement for adequate seed viability, many pasture plants are recent selections from wild species, some of which have persistent seed dormancy mechanisms. Of significance for pasture establishment are embryo dormancy, mainly in tight-husked grass seeds, and strongly developed hard-seededness or water impermeability in the seeds of some legumes (Hopkinson 1993).

The establishment system is defined in this paper most broadly as: *a continuum of phases and processes from the production of a seed crop to the stage when production or resource-maintenance benefits from the developing forage resource are achieved.*

System phases

The establishment continuum can be divided into 8 phases (Figure 1). Four seed supply phases govern seed properties pre-sowing (viability and dormancy) and 4 field establishment phases span the transition from sown seeds through to well established plants. The system can be simplified to just the last 3 phases for highly domesticated pasture and forage crop species as they usually have high seed viability and little or no seed dormancy.

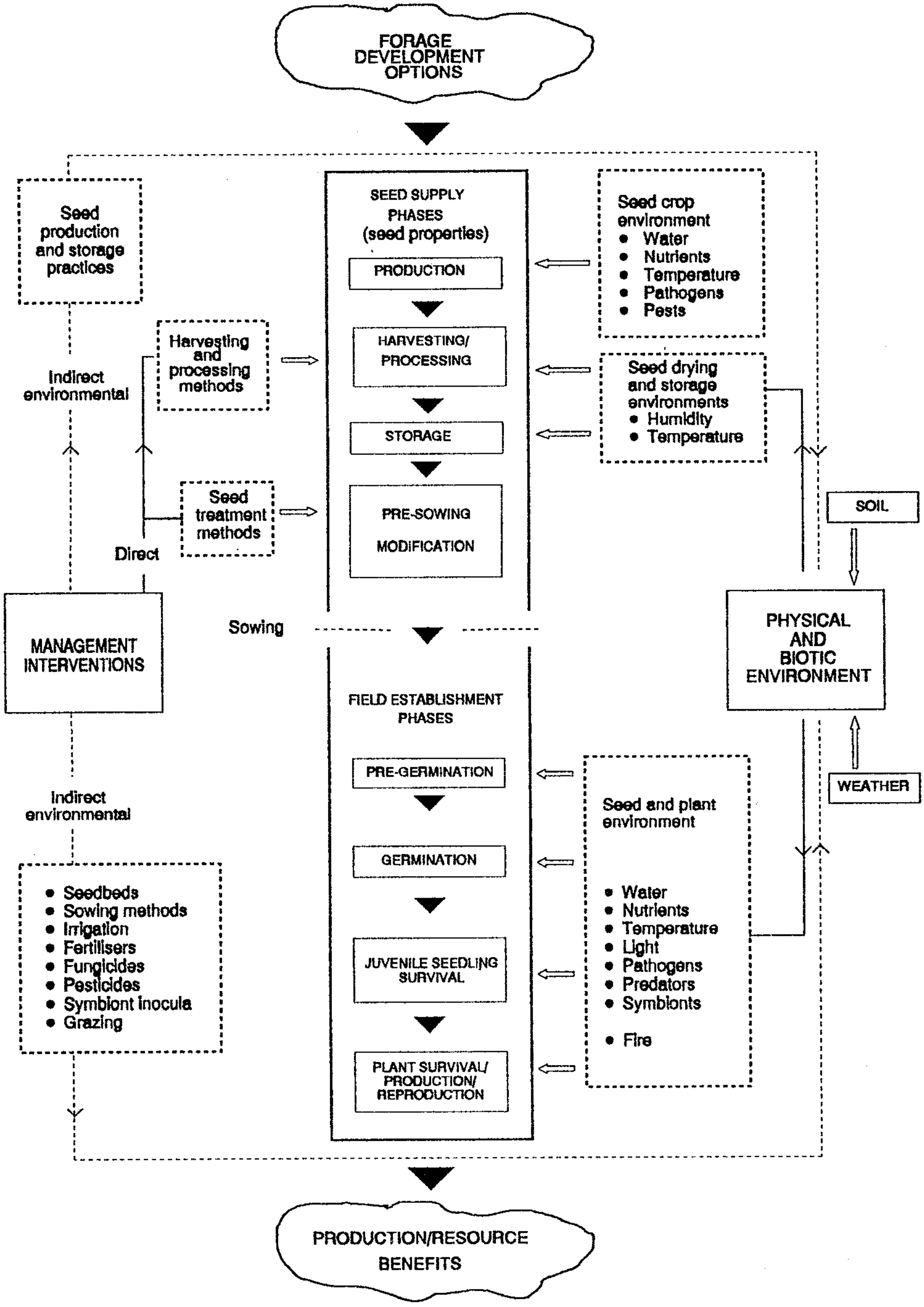


Figure 1. System schema of sequential phases for pasture and forage crop establishment and of key biological, environmental and management variables influencing establishment outcomes.

System variables

Besides the particular seed properties and plant morphological, growth and reproductive characteristics of the species being established, there are 2 principal sets of system variables: the external physical and biotic environment; and management (Figure 1). The environmental and management variables are closely interlinked; that is, most management interventions modify the environment of seeds throughout all phases from seed production to germination, or of the establishing and growing plants following germination. Management may also directly modify seed properties, either through practices used for harvesting and processing seeds, or through seed treatments deliberately imposed pre-sowing to reduce dormancy or improve handling.

Figure 1 embraces many of the important environmental and management variables but these are not claimed to be exhaustive. Variables important for the establishment of particular tropical pasture species are highlighted and elaborated upon further in this paper and in other papers of this issue of Tropical Grasslands.

The system phases

Seed supply

Perennial shrubby stylo is a most appropriate species for illustrating how the seed supply phases may influence establishment. As background, it possesses a high degree of seed dormancy, mainly as hardseededness. It also has embryo dormancy but, as with most other pasture species except grasses with tight-husked seeds, this form of dormancy is usually short-lived and of limited significance for field establishment (Gardener 1975; Hopkinson 1993). Physical disruption of the seed coat and related structures reduces hardseededness and, under field conditions, natural hard seed breakdown or 'softening' is characteristically related to the summation of day-degrees >50 °C that seeds experience at the soil surface (Mott *et al.* 1981).

Seed production. Links between the environment experienced by developing and ripening seeds and the degree of seed dormancy have been demonstrated for a wide range of species, although the causal factors are only equivocally defined (Fenner 1991). High temperatures and drought increase hardseededness in legumes (Argel and Humphreys 1983; Hill *et al.* 1986), but low temperatures and favourable moisture conditions appear to lead to greater embryo dormancy in other species, including grasses (Fenner 1991).

Hardseededness and embryo dormancy may therefore vary not only between species but also between seed sources within a species. For example, shrubby stylo seed from different sources differs substantially in the rate of seed softening (Figure 2). Further, using an index of hardseededness based on cumulative day-degrees >50 °C required to soften 50% of the hard seed, we found these differences were closely related to initial seed moisture content. This may be general for hardseeded legumes since data for 2 temperate legumes (Quinlivan 1971), and ours for shrubby stylo, can be expressed relative to the degree of hardseededness measured at the lowest seed moisture content examined for each species (narrow range from 6.7–7.4% moisture) to show an apparently common relationship (Figure 3). Such a relationship is compatible with high temperature and drought effects increasing hardseededness as previously noted.

The presence of important diseases in a seed crop may become a source of inoculum for infection of plants establishing from these seeds. Anthracnose (*Colletotrichum gloeosporioides*) borne on stylo seed pods is one example (Davis 1987).

Seed harvesting, processing and storage. Different methods of harvesting and the timing of harvest relative to seed maturity influence germination and dormancy characteristics. With shrubby stylos, suction harvesting may produce seed with less hardseededness than header harvesting because fallen seed may undergo some softening before harvest. With grasses, germination and dormancy can vary according to the ratio of immature to mature seed harvested (Hopkinson 1993).

Harvesting, processing and storage methods also influence seed viability, with seed best retaining viability and protection from pathogens and insects when it is dried to low moisture content and stored at low temperatures (Roberts 1986). They may also modify the barriers to germination of viable seeds, as when mechanical abrasion during harvest reduces legume hardseededness or cold storage prolongs grass seed dormancy.

Consideration of these phases may be particularly important when tracing the cause of

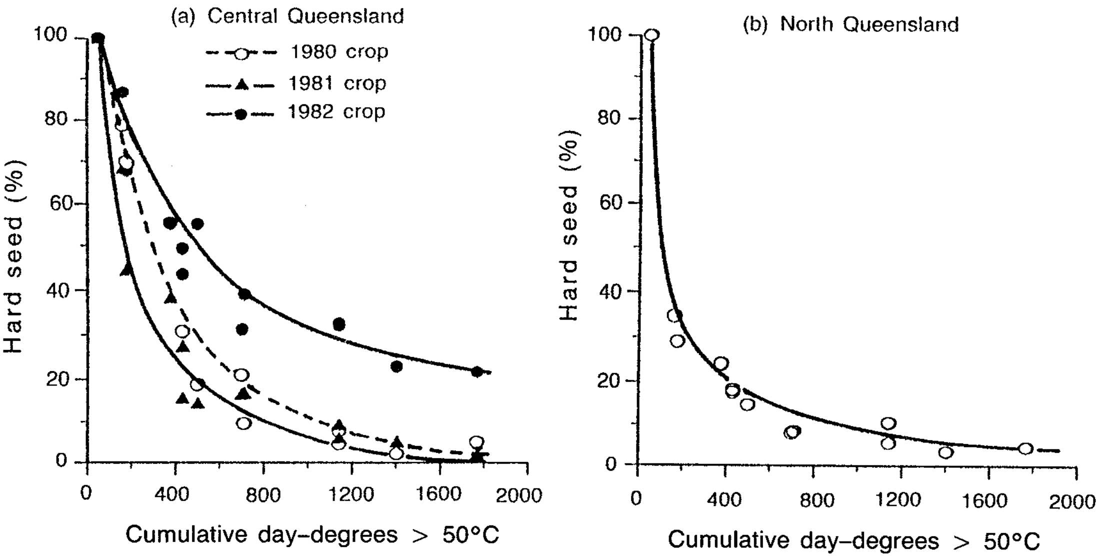


Figure 2. Patterns of softening of hard seed in Fitzroy stylo in response to cumulative day-degrees >50 °C experienced at the soil surface: (a) 3 consecutive seed harvests from the same crop area in central Queensland; (b) seed harvested in north Queensland. Curves are eye-fitted.

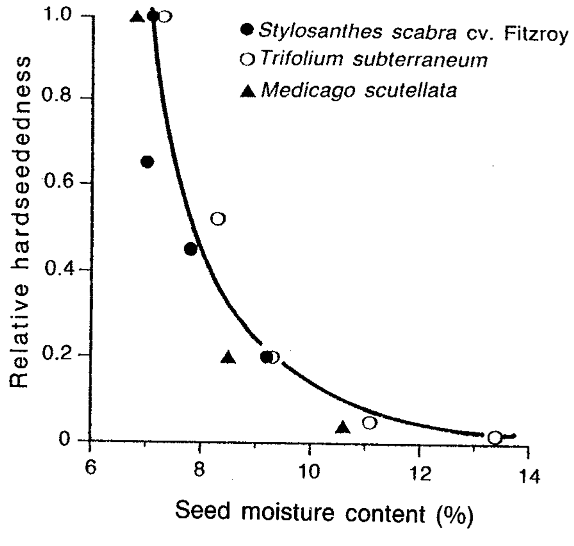


Figure 3. Common relationship between 'hardness' of hard seeds and seed moisture content in tropical and temperate pasture legumes. For each species, 'hardness' is expressed relative to the hardest seed lot tested for that species, with relative indices of hardseededness for each seed lot derived from seed softening patterns: for shrubby stylo, the day-degrees >50 °C needed to soften 50% (from Figure 2); for subclover and snail medic, the number of weeks to soften 20% or 10% of the hard seed, respectively, under standard conditions (after Quinlivan 1971).

establishment failures with seeds opportunistically harvested, stored and sown on-farm. Specialist seed producers and merchants usually ensure their product is of a high standard.

Pre-sowing dormancy modification. In practice, this is confined to treatments that physically modify seed coats and structures. With legumes, dehulling of podded seeds and mechanical scarification are used to fracture the testa to permit rapid water imbibition and germination, while heat treatment, usually a brief exposure of seeds to high temperature, breaches the strophiole with a more benign effect on germination rate (Hopkinson 1993; Hopkinson and Paton 1993).

Field establishment

Pre-germination, germination and juvenile seedling establishment. These 3 field establishment phases are considered together because they are strongly interlinked and most dynamically influence establishment outcomes. Many interactions occur between seed or seedling properties and the micro-environments experienced by the seeds or seedlings (Cook 1980; Silcock 1980), and these are often amplified when more risky, low input establishment methods are used. Water availability to seeds, and water and nutrient availability to developing seedlings are dominant factors. Most management practices aim to improve the supply of these growth factors by extending the time over which seeds are in contact with moist soil (e.g. mulches, sowing depth, sowing time) or by reducing or eliminating competition for water and nutrients (e.g. control of competing vegetation or weeds, fertiliser application, rhizobial inoculation of legumes).

In the pre-germination phase, 2 weathering processes can modify potential germination behaviour of oversown shrubby stylo. As already noted, natural softening of hard seed occurs at high soil surface temperatures. Also, rainfall events insufficient for germination of all or part of the soft seed population increase the potential germination speed of the residual seeds (McKeon and Brook 1983; McKeon 1984), as shown more predictively through our data in Figure 4. An analogous response in grasses is the phenomenon of hydropedesis reported for tropical grass seeds by Watt (1974). With grasses, it is not so clear how changes in embryo dormancy after sowing into soil influence subsequent germination (Hopkinson 1993).

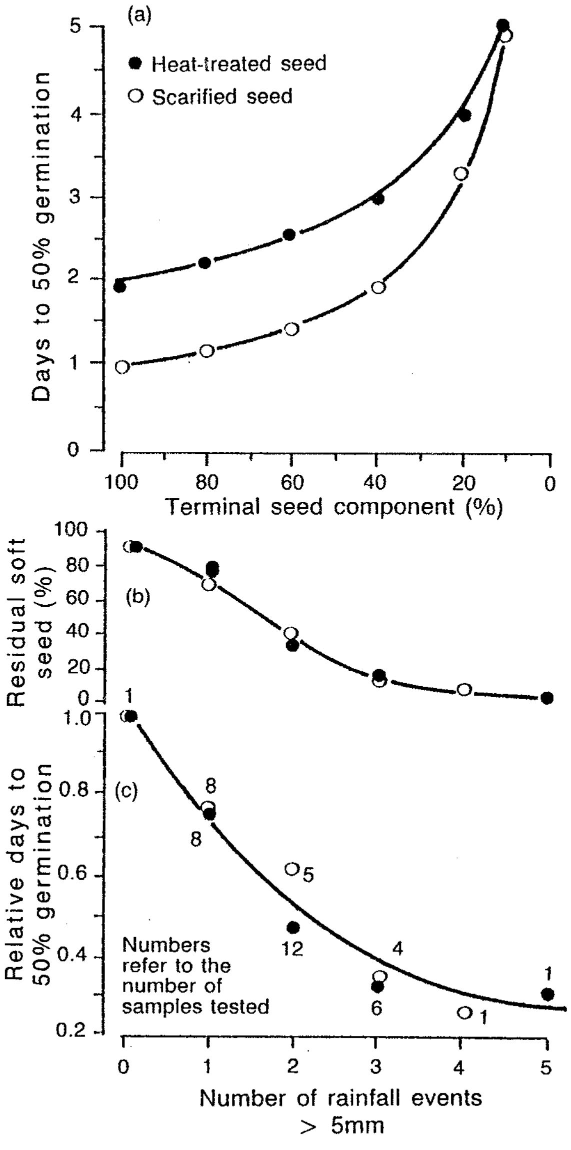


Figure 4. Germination speed of softened Fitzroy stylo seed before sowing and following field weathering: (a) germination speed before sowing of decreasing terminal or potentially residual seed fractions of the seed population (such as after partial germination) of heat-treated and scarified seeds derived by partitioning cumulative germination curves; (b) mean residual soft seed recovered from the field after different rainfall histories; (c) relationship between mean relative speed of germination (speed of residual seed recovered from the field divided by the initial speed of the same seed fractions) and rainfall history during field weathering. Curves are eye-fitted.

Seed losses from predation, such as seed harvesting by ants and termites, can be substantial during the pre-germination phase if seed is surface sown a long time before the germination event (Norman 1961; Mott and McKeon 1977).

Germination of oversown seed often occurs in a transient surface moisture environment. The proportion of non-dormant seed germinating is therefore sensitively determined by the potential germination speed of the seeds and the time for which they remain adequately imbibed. Consequently, the duration and distribution of rainfall events have a strong influence on germination (McKeon and Brook 1983).

Temperature influences speed of germination but the interaction of low temperatures with longer duration of adequate surface moisture reduces the limiting effect of temperature. For example, we found that shrubby stylo could successfully establish from winter sowings.

Following radicle emergence in oversown seed, the development and survival of juvenile seedlings becomes a race between root elongation and the receding drying front down the soil profile. This is demonstrated for shrubby stylo through a strong relationship between the daily death rates of juvenile seedlings and the available water deficit in the root zone, a relationship which becomes more severe under conditions of high evaporative demand (Figure 5). Marginal moisture supply at this critical stage can cause a 'false germination' in which all of the germinated seed fails to produce juvenile seedlings. A satisfactory establishment outcome then depends on succeeding waves of germination, provided sufficient viable seed remains.

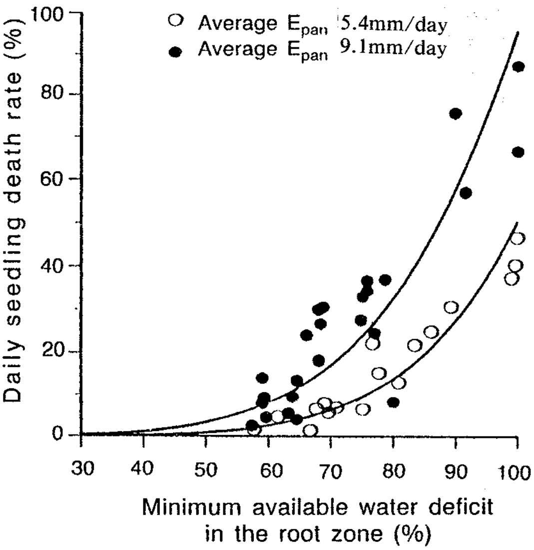


Figure 5. Daily death rates of juvenile Fitzroy stylo seedlings under low (April) and high (November) evaporative demand in response to the minimum deficit of available soil water in the root zone. Data were generated by contriving contrasting available water profiles near the surface of an alluvial soil followed by intensive daily monitoring of root elongation, seedling survival and soil water content (0–2, 2–5 and 5–10 cm layers) over 7 days following the germination of seed on the soil surface.

Plant survival, production and reproduction. Once juvenile seedlings have established they are still most susceptible to constraints which influence plant survival, growth and reproduction. Important ones include: competition, or even sometimes allelopathic interference, from cohabiting plants; predation by grazing animals, insect pests and diseases; and frost injury, especially with tropical pasture species (Humphreys 1981; Cook *et al.* 1993; McIvor *et al.* 1993).

Briefly expanding on competitive effects, establishing legumes suffer competition mostly for water, whereas other plants without the advantage of symbiotic nitrogen fixation experience significant competition for nitrogen as well. Oversowing of grasses into established grass is most hazardous. Species with slow seedling growth rates, like some perennial shrub and tree legumes, are also especially vulnerable to competition.

Using data from oversowings of shrubby stylo on different sites and seedbeds, we demonstrated a relationship between post-juvenile seedling mortality and a water stress index calculated as a function of soil water deficit and pan evaporation (Figure 6). The relationship is similar to those developed for juvenile seedlings (Figure 5) in that seedling deaths occurred only when the available water deficit in the root zone exceeded about 40%. The precision of the relationship is not as good as that for juvenile seedlings probably because water deficits were calculated with a 2-layered (0–10 cm and 10–50 cm) soil water balance (Rickert and McKeon 1982). Nevertheless, this preliminary analysis suggests a common and dominant association between legume seedling mortality and water stress across different soil and vegetation associations. It also emphasises the greater water stress and associated mortality of seedlings when they establish in competition with resident grasses.

The predictive accuracy of the relationship in Figure 6 would be enhanced by an improved characterisation of rooting patterns and soil water availability, particularly with strongly texture contrast soils. In these soils, water movement and root behaviour at the junction of the disparate soil horizons may have considerable influence on establishing plants.

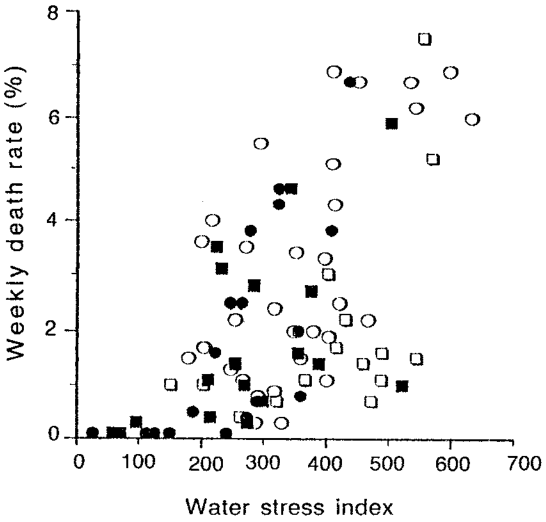


Figure 6. Relationship between average weekly death rates of Fitzroy stylo seedlings between age 10–73 days and a water stress index. Data are from 4 oversowings (January, June, December and February) into glyphosate-sprayed (solid symbols) and mown (open symbols) seedbeds at each of 4 soil-grass sites, with red earth-native pasture, granitic duplex-native pasture and alluvial-buffel grass site data pooled (circles) and compared with more variable data from a brigalow duplex-buffel grass site (squares). Death rates derive from seedling losses observed at 21 day intervals, expressed as an average weekly death rate for the period. The water stress index is the daily available soil moisture deficit in the root zone averaged over the 21-day period, multiplied by average daily evaporation. Depending on estimated rooting depth, the lowest or minimum deficit of either the 0–10 cm or the 10–50 cm layer was used. Available water in the 2 soil layers was simulated through a water balance model tuned against direct field measureents.

In the above and other similar field studies, we measured a 5–50-fold growth advantage of stylo plants by the end of the growing season where competition was removed by glyphosate spraying before sowing. These responses were in a similar range to those reported by Cook and Ratcliff (1985) for Siratro (*Macroptilium atropurpureum*) and green panic (*Panicum maximum* var. *trichoglume*) when root and shoot competition were eliminated.

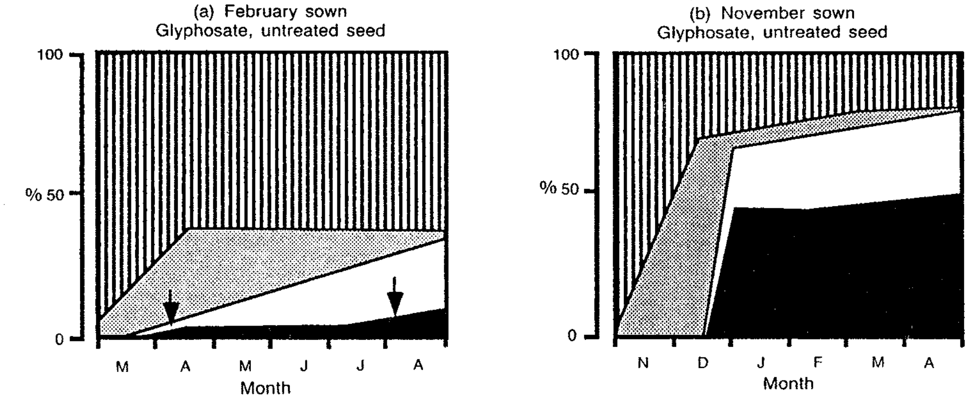
Grass competition delays seedling development (enforced juvenility) and inhibits flowering and seed production (Humphreys 1981). Again, in our studies, shrubby stylo seedlings establishing without competition from grasses in the period from early summer to early autumn always flowered and set seed by winter, whereas those with competition did not reproduce until the next growing season.

Understanding or predicting the impact of frost on establishment is most difficult due to many confounding variables such as frost severity, micro-topographic effects, the height of the primary plant apices above ground level, and the possibility of cold conditioning which includes interactions with plant water status (Humphreys 1981). Plant death due to frost cannot, however, be neglected in inland subtropical or high altitude tropical regions. With shrubby stylo in the inland subtropics, we recorded plant mortalities exceeding 80%, irrespective of plant size, over a winter season with severe frosting (19 days of screen temperatures less than 2 °C and a lowest terrestrial minimum of −6.0 °C). Further, larger (and taller) plants growing without severe grass competition appeared to be more tolerant of moderate frosting (0–25% mortality) than nearby plants in a state of enforced juvenility due to competition (25–55%).

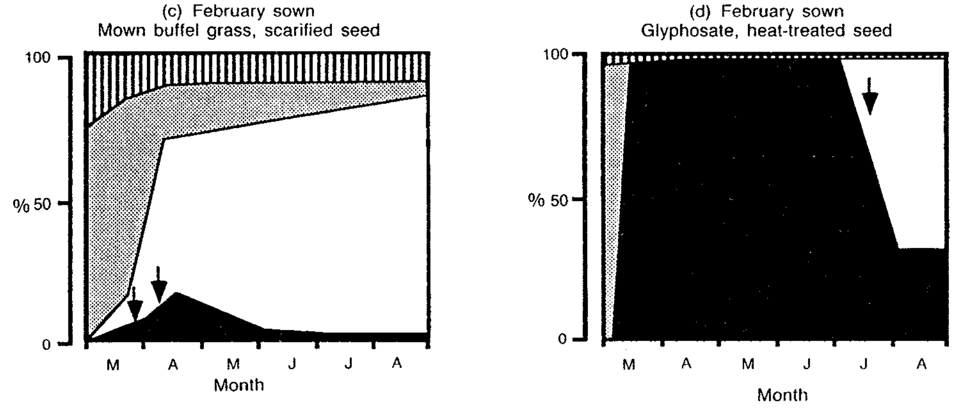
Some contrasting results from experimental sowings of shrubby stylo seed are presented in Figure 7. These highlight some of the regulating factors we have described for the field establishment phases.

Establishment risks

Rapid and reliable establishment is mandatory for pastures and annual forage crops that play an essential role in livestock feeding schedules aimed at high production, e.g. milk production


(a) February sown
Glyphosate, untreated seed

(b) November sown
Glyphosate, untreated seed


(c) February sown
Mown buffel grass, scarified seed

(d) February sown
Glyphosate, heat-treated seed

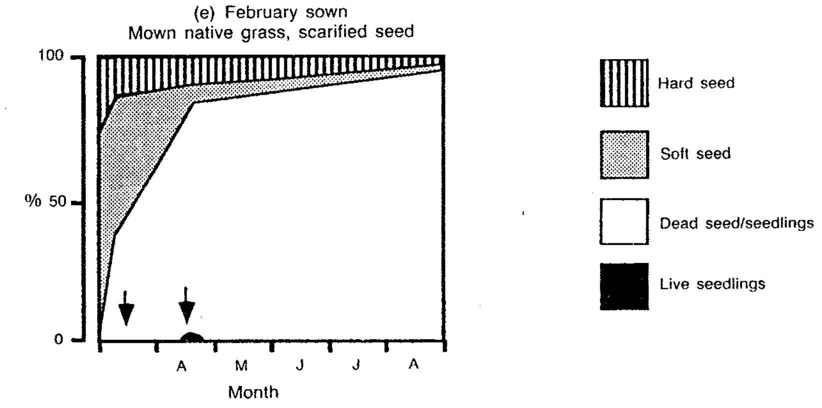

(e) February sown
Mown native grass, scarified seed

Figure 7. Contrasting examples of the possible fates of sown seed and of establishing seedlings of Fitzroy stylo oversown in different seasons into either glyphosate-sprayed or mown seedbeds: (a) restricted softening of hard seed (sum day-degrees $>50\,^{\circ}\mathrm{C}$ = 162), limited rainfall, 2 small seedling waves (arrows); (b) substantial seed softening (sum day-degrees = 1064), favourable rainfall; (c) limited rainfall, two seedling waves (arrows), severe plant mortality due to water stress exacerbated by grass competition; (d) complete germination and seedling establishment of soft seeds under a simulated, prolonged rainfall event (irrigation), severe plant losses later due to frost (arrow); and (e) limited rainfall, establishment failure due to 2 'false germinations' (arrows). The changing status of sown seed was assayed by placing seed in recoverable mesh bags in close contact with the soil surface.

and intensive beef finishing. Risks with these forages are usually low, however, because they are mainly used in environmentally endowed locations and there is scope within the enterprises to increase management inputs profitability, including the use of irrigation.

For more extensive, low input pasture development situations, higher establishment risk is inevitable, especially in marginal rainfall environments. With lower and more variable rainfall, and restricted opportunities to improve water supply to seeds and seedlings, low cost practices that might minimise risk become attractive. However, quantitative risk or probabilistic assessment of sowing methods is seldom reported, simply because observations of establishment outcomes fail to sample enough rainfall sequences for valid analyses. One notable exception is the computer simulation approach used by Leslie (1984) to help determine management decisions that could improve the reliability of establishment of small seeded tropical grasses when drilled into cracking clay soils.

Without an equivalent analysis for legume oversowing, we consider 3 independent data sets on establishment of shrubby stylo obtained by us and M.J. Quirk (personal communication) are collectively adequate to provide insights into establishment risks. The data are from oversowings of untreated, heat-treated or scarified seeds into mown or glyphosate-sprayed native or sown grass swards, principally black speargrass (*Heteropogon contortus*) and buffel grass (*Cenchrus ciliaris*); in all, a total of 150 summer season sowings over 10 sites in subtropical central (1984–85 and 1986–88 sowing sequences) and south-east (1988–92 sowing sequence) Queensland.

Probability curves of establishment percentages, recorded at the end of the summer season in which seeds were sown, are shown for selected groupings of data from each of the 3 sowing sequences in Figure 8. In more than half of the 86 sowings into mown grass with untreated or ineffectively treated seeds, fewer than 5% of seeds sown produced established plants. Good establishment, for example say >20%, was achieved in only 10–15% of sowings. Seed treatment only marginally increased reliability, except for a substantial benefit from heat-treated seed in the 1984–85 sequence (Figures 8a, 8c). In this case, a well controlled, experimental heat treatment softened most hard seed without any confounding seed mortality, a problem now known to prevent reproducibility of beneficial seed responses from presently available commercial-scale heat treatments (Hopkinson and Paton 1993). Removal of competition from resident grasses appreciably increased establishment reliability (Figure 8b).

A close correspondence among derived probabilities for orthogonal groups of data from each of the sowing sequences (Figure 8d) provides a measure of confidence in the validity of the analyses, despite the small number of sowings for each derivation. Nevertheless, the limitations of this approach need to be emphasised. The assessment is related only to the number of plants establishing within the season of sowing and does not include plant growth and reproduction aspects, frost effects or subsequent colonisation dynamics. Also, the analyses allow neither extrapolation to other environments nor a dynamic decision support capability such as would be achievable through systems simulation.

Based on the foregoing, a family of probability curves is postulated for establishment outcomes (Figure 9). Diagonally from the origin is a gradient from 'low input — high risk — protracted establishment' to 'high input — low risk — rapid establishment'. Extensive pasture establishment using oversowing without seedbed modification or seed treatment is near the origin (curve 1) and high precision methods, such as those used for intensive crops, are at the other extremity (curve 6). As an intermediate example, establishment of 40–70% is normally achieved with broad-area grain crop sowings in Queensland (B. Radford, personal communication), which may be represented by curve 4. Finally, the generic presentation helps visualise the potential shifts away from the origin that are possible as establishment methods are improved or sowing environments become more benign. For example, risks with band-seeding in the inland subtropics of Queensland might be expected to be intermediate to those experienced with legume oversowing and grain cropping (perhaps between curves 2 and 3), and the establishment of forage crops under irrigation would have minimal risks (curves 5 to 6).

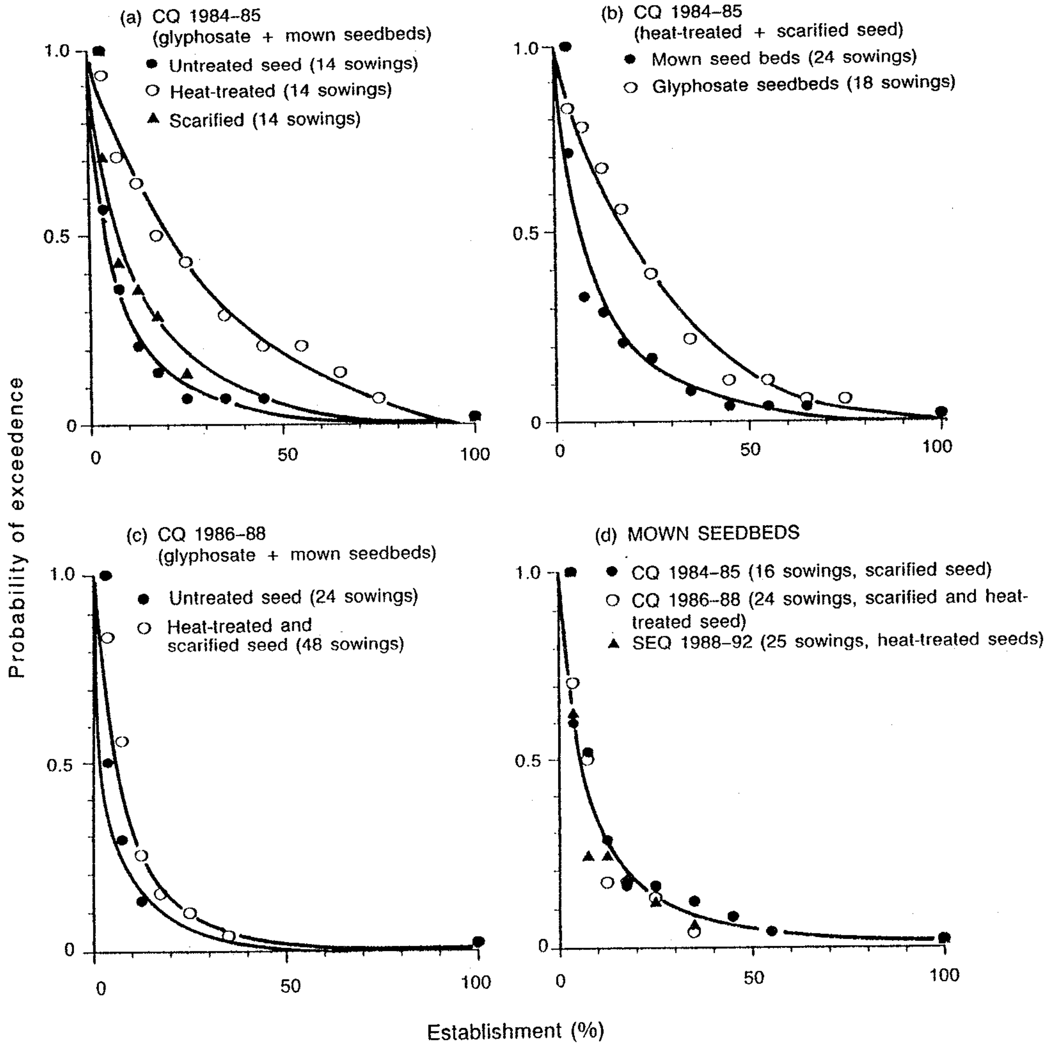


Figure 8. Probability curves of establishment percentages from oversown shrubby stylo at the end of the summer sowing season calculated from 3, independent sowing sequences in the medium rainfall (annual average 700-800 mm) subtropics of central (CQ) and south-east (SEQ) Queensland. Establishment data from different seedbeds and seed treatments are variously selected or grouped to orthogonally compare the effects of management and sowing seasons on establishment risks. Curves are eye-fitted.

Pasture development rate and economic outcomes

Development rate

The transition period from well established, young plants to a usable and profitable forage resource may vary widely. In high input pasture and annual forage crop sowings, the transition normally takes only from a few weeks to a few months. In low input sowings, particularly with slow growing perennial plants like shrubby stylo or some browse species, the lag time to production benefits may extend over years. Experiences with low input, commercial-scale legume sowings in the seasonally dry tropics of

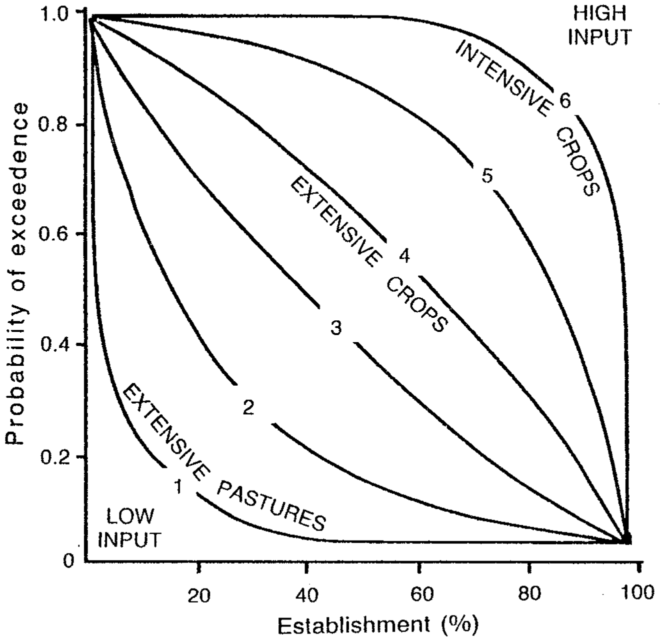


Figure 9. Generic family of probability curves for plant establishment. Curves 1–6 represent a gradient of decreasing environmental constraints, increasing management inputs, increasing reliability and decreasing lag times for production benefits.

north Queensland, for example, indicate that it may be 8 years before legume contribution is significant (Anon. 1992). Similarly, grasses sown in tropical legume-grass mixtures may take from 6–8 years to make a substantial contribution to forage supplies (McIvor *et al.* 1993).

Many valuable research studies have described how introduced tropical species increase or fluctuate in their contribution within developing pastures, as well as providing insights into plant persistency and regenerative mechanisms and the interactions between these and management. These aspects differ among species and were reviewed by McIvor *et al.* (1993).

Systems approaches for analysing and predicting rates of pasture development have yet to be vigorously pursued. Quantitative approaches and conceptual models of population dynamics in species mixtures developed and reported by Torssell and Nicholls (1978) may provide a prototype.

Economic outcomes

A partial economic analysis by A.M. Jamieson (personal communication) and D. Gramshaw (unpublished data) is presented as the final aspect of a systems perspective on pasture establishment. Internal rates of return on investment (IRR) were calculated for beef production from shrubby stylo-based pastures involving low and high input scenarios. Four scenarios are presented (Figure 10) to highlight the economic consequences of different pasture development rates and of an establishment failure. They are based on conservative estimates of lag times to increased production and the corresponding potential of the developing pastures to increase cattle liveweight and carrying capacity.

The analyses suggest that an IRR of 0.25–0.37 or 0.17–0.33 should be achievable from pasture development when the beef industry is buoyant or depressed, respectively, provided potential increases in beef production are achieved in the year following sowing (Figures 10a, 10c, 10d). A lag of 4–5 years before achieving maximum liveweight gain/head or maximum carrying capacity with oversown stylo halved the return on investment (Figures 10a, 10c) to values similar to that reported by Wicksteed (1985). An establishment failure and re-sowing resulted in a financial loss unless the beef industry was buoyant and

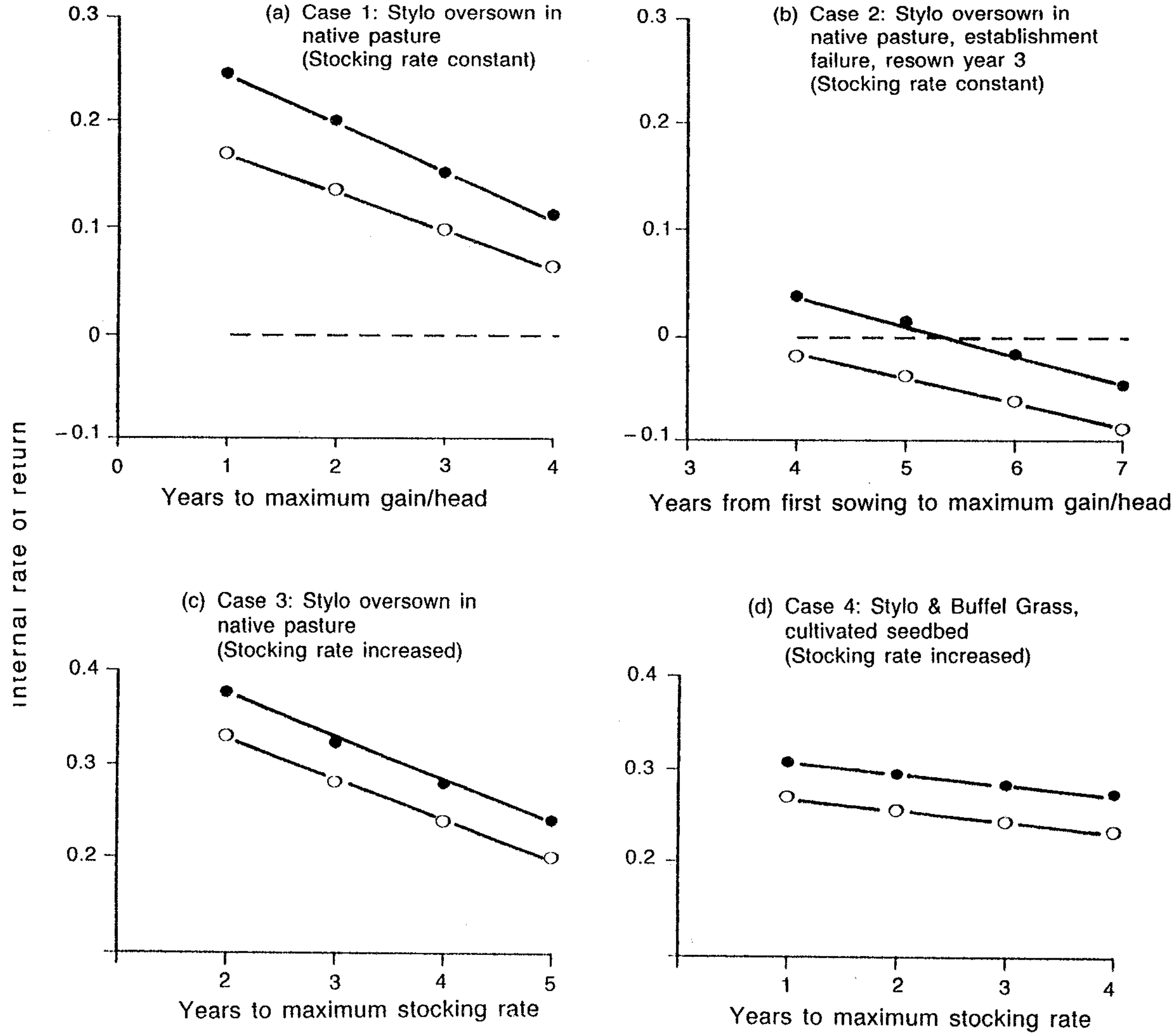


Figure 10. Internal rate of return on investment for beef production from 4 shrubby stylo establishment and development scenarios when the beef industry is either buoyant (●) or depressed (O).

Inputs and variables

Life of development: 10 years
Monetary inflation: Nil
Cattle prices (¢/kg):
  store cattle — 120 (buoyant); 80 (depressed)
  finished cattle — 120 (buoyant); 90 (depressed)
Establishment costs ($/ha):
  Cases 1 and 3 — 32; Case 2 — 64;
  Case 4 — 79
Cattle management costs ($/ha):
  unimproved — 23; improved — 25

Average liveweight of store cattle: 375 kg
Annual weight gain (kg/hd):
  unimproved — 110; maximum improved — 150
Stocking rate (hd/ha):
  unimproved — 0.25;
  maximum improved — Case 3 — 0.50;
    Case 4 — 0.75

potential productivity gains were realised within 2 years of resowing (Figure 10b). A smaller penalty from delays in increasing carrying capacity is indicated for fully developed pastures (Figure 10d); this reflects the cost of the additional cattle purchases required to exploit the higher carrying capacities of these pastures.

These data strongly support an investment in developing cost-effective technologies for improving establishment reliability and the rate of pasture development for oversowing methods. However, the harsher the establishment environment, the less likely such advances are achievable.

Conclusions

An holistic systems approach to pasture and forage crop establishment requires an integrated appreciation of biological, environmental, management and economic aspects. It is of benefit in providing a problem-solving framework especially relevant to complex and high risk establishment situations, like those experienced with low input establishment methods and which involve recently domesticated or native species possessing well developed seed dormancy mechanisms.

Constraints to successful establishment may occur in one or a number of the sequential phases of the establishment continuum, extending from the production of seed to when the sown species makes an economic contribution through either production or resource-maintenance benefits. With low input legume oversowing, hardseededness and seed germination characteristics are important, rainfall patterns have a dominant influence and competition from other plants is critical. Further, management interventions may often be equivocal, simply because improvements in one phase or process may be negated by failures in others and specific interventions may be beneficial or detrimental depending on weather patterns. Robust management recommendations under these circumstances are difficult without predictive risk analysis, such as could be achieved through systems simulation and more accurate weather forecasting.

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