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PASTURE ESTABLISHMENT THROUGHs LINE PLANTING AND BROADCASTING TECHNIQUES: A COMPREHENSIVE REVIEW OF METHODS, PRACTICES, EFFICIENCY, AND RECOMMENDATIONS

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ABSTRACT

Pasture establishment represents one of the most critical agronomic investments in livestock and ruminant production systems globally. The choice of planting method — whether line planting (drill or row seeding) or broadcasting (surface or aerial seed dispersal) — profoundly influences seedling emergence, stand density, uniformity, weed competition, long-term forage yield, and the overall economic sustainability of the pasture enterprise. This review critically examines the agronomic, ecological, economic, and management dimensions of both methods across diverse agro-ecological zones, with particular emphasis on tropical and sub-tropical production systems relevant to sub-Saharan Africa, Latin America, and South and Southeast Asia. Evidence from controlled experiments, farm surveys, and long-term agronomic trials is synthesised to evaluate the comparative performance of each method under varying soil types, rainfall regimes, species compositions, and management intensities. The review further discusses species-specific considerations, seeding rate optimisation, soil preparation requirements, post-establishment management, and the emerging role of precision seeding technologies. Findings indicate that line planting consistently delivers superior stand establishment, higher long-term forage productivity, and better weed suppression, while broadcasting offers cost-effective, large-scale application advantages particularly in rough terrain and when species diversity is prioritised. A decision framework integrating farm-specific factors is proposed to guide practitioners in selecting the most appropriate method. The review concludes with evidence-based recommendations for integrating the two approaches under complementary conditions to maximise pasture establishment success.

Keywords: Pasture establishment; line planting; broadcasting; forage production; stand uniformity; seeding methods; tropical pastures; agronomy

1. INTRODUCTION

Pastures form the foundational productive base of all grazing-based livestock systems, supplying the bulk of dietary energy, protein, and dry matter requirements for ruminant animals including cattle, sheep, goats, and buffalo. In sub-Saharan Africa, Latin America, and South Asia, natural and improved pastures underpin the livelihoods of hundreds of millions of smallholder and commercial livestock farmers, making their successful establishment and management a matter of both national food security and rural economic stability (FAO, 2023; Herrero *et al.,* 2013).

The establishment phase of pasture development is widely recognised as the most critical determinant of long-term pasture productivity and persistence. Failures at establishment — whether arising from poor seed-to-soil contact, inadequate seedbed preparation, inappropriate species selection, or suboptimal planting methods — impose costs that cannot easily be recovered through subsequent management interventions (Humphreys, 1991; Cook *et al.,* 2005). It is estimated that pasture establishment failures cost the livestock industry billions of dollars annually in wasted seed, labour, and deferred production globally (Miles *et al.,* 2004).

Central to the establishment decision is the choice between two principal seeding methodologies: line planting (also referred to as drill seeding, row planting, or precision seeding) and broadcasting (surface seeding, aerial seeding, or scatter seeding). These methods differ fundamentally in their mechanics, resource requirements, soil interactions, ecological consequences, and outcomes in terms of stand density, uniformity, and persistence. Yet the comparative literature remains fragmented across species types, agro-ecological zones, and production systems, creating ambiguity for practitioners who must make planting decisions with limited access to consolidated evidence.

This review addresses that gap by synthesising the global and tropical literature on pasture establishment methods, comparing line planting and broadcasting across a comprehensive array of agronomic, ecological, economic, and practical dimensions. It aims to provide practitioners, researchers, extension workers, and policymakers with a rigorous, evidence-based reference that facilitates informed decision-making in diverse pastoral contexts.

1.1 Scope and Organisation of the Review

This review covers tropical, subtropical, and temperate pasture systems, with particular depth in tropical grass and legume species relevant to Africa, Latin America, and Asia-Pacific. It is organised into sections addressing: (i) the agronomic principles underlying establishment success; (ii) detailed characterisation of line planting and broadcasting methods; (iii) comparative performance across key parameters; (iv) species-specific considerations; (v) economic analysis; (vi) ecological and environmental dimensions; (vii) emerging technologies; and (viii) an integrative decision framework and recommendations.

2. AGRONOMIC PRINCIPLES UNDERLYING PASTURE ESTABLISHMENT SUCCESS

Successful pasture establishment is governed by a hierarchy of interacting agronomic factors. Understanding these principles is prerequisite to evaluating how each planting method performs.

2.1 Seed Germination and Seedling Emergence Requirements

Germination in pasture species requires the simultaneous fulfilment of moisture, temperature, light, and oxygen thresholds. The critical seed-to-soil contact — defined as the physical proximity of the seed to moist soil particles that enables capillary water uptake — is perhaps the single most important determinant of germination success across all planting methods (Humphreys, 1991). Seeds placed on the soil surface without incorporation are susceptible to desiccation, avian predation, wind and water dispersal, and UV-induced dormancy loss. Conversely, seeds buried too deeply (typically >2–3 cm for small-seeded tropical grasses) exhaust cotyledonary reserves before emergence and suffer establishment failure (Loch and Ferguson, 1999).

Small-seeded species such as Stylosanthes spp., Centrosema spp., and Brachiaria spp. are particularly sensitive to seeding depth. Their optimal placement depth of 0.5–2.0 cm demands precision that broadcasting cannot guarantee without secondary incorporation, while line planting achieves this through calibrated opener mechanisms (Cook and Dias, 2006).

2.2 Seedbed Preparation

The quality of seedbed preparation directly conditions the efficacy of both planting methods. A fine, firm, weed-free seedbed maximises seed-to-soil contact, reduces competition, and supports uniform moisture distribution (Carlson *et al.,* 2010). However, excessive tillage on fragile tropical soils can

accelerate erosion, destroy soil structural aggregates, and expose subsoil layers with poor fertility. Minimum tillage or zero-till approaches are therefore increasingly advocated, particularly in sub-humid and semi-arid tropical environments, and favour broadcasting into standing vegetation or residue-covered soils where direct drilling is not available (Fisher and Kerridge, 1996).

2.3 Weed Competition

Weed competition represents the dominant biotic constraint to pasture establishment in tropical environments. The critical weed-free period — the duration following germination during which pasture seedlings must be protected from weed competition to achieve productive establishment — varies by species but generally spans the first four to eight weeks after emergence (Humphreys, 1991; Cook *et al.*, 2005). Planting methods that promote rapid canopy closure and uniform ground cover are therefore inherently superior in weed suppression, giving line planting a structural advantage in high-weed-pressure environments.

2.4 Soil Moisture Dynamics

The temporal and spatial distribution of soil moisture during the planting window critically determines germination and early seedling survival. In semi-arid and seasonally dry environments, planting in rows concentrates moisture-accessing root biomass and reduces evapotranspiration demand per plant, while broadcast seedlings face a more competitive moisture environment due to random spatial dispersion (Loch and Ferguson, 1999). In humid environments with reliable rainfall, this distinction diminishes, and broadcasting may achieve adequate establishment.

2.5 Fertiliser and Nutrient Management

The placement of nutrients relative to seeds at establishment significantly influences early seedling growth. Banded fertiliser application — achievable with line planting through seed-and-fertiliser drill configurations — places nutrients within the rhizosphere zone accessible to germinating seedlings, maximising fertiliser use efficiency. Broadcasting of fertiliser, by contrast, distributes nutrients uniformly across the soil surface, with a greater proportion subject to volatilisation (nitrogen), surface run-off, and luxury consumption by weeds before pasture seedlings can access them (Jones, 2002).

3. LINE PLANTING: CHARACTERISTICS, MECHANICS, AND PERFORMANCE

3.1 Definition and Methodological Variants

Line planting, also referred to as drill seeding, row planting, or precision seeding, involves the placement of seeds at a predetermined depth and spacing in continuous rows or lines using mechanical or hand-operated seeders, drills, planters, or dibble sticks. The method encompasses a spectrum of mechanisation levels, from manual jab planters used in smallholder systems to sophisticated GPS-guided pneumatic precision drills used in large-scale commercial operations (Loch and Ferguson, 1999; Carlson *et al.,* 2010).

The principal variants of line planting include: (i) direct drilling (no-till row seeding into undisturbed soil or existing sward residue); (ii) cultivated drill planting (row seeding following full or minimum tillage); (iii) inter-row or inter-crop planting (rows established between existing crop or pasture rows); (iv) ridge-and-furrow planting (rows placed in furrows to concentrate surface moisture); and (v) vegetative line planting (placement of stem cuttings, stolons, or tillers in rows — applicable to species such as Pennisetum purpureum and Paspalum notatum) (Cook *et al.,* 2005).

3.2 Equipment and Technology

The efficiency of line planting is closely linked to the availability and appropriateness of equipment. Commercial grain drills adapted for small-seeded forage species represent the most common mechanised approach, with key modifications to metering systems to accommodate the light, fluffy, or chaffy seed types common in tropical grasses. Seed metering accuracy, opener type (disc, tine, or hoe), depth control mechanisms, and seed tube design all critically influence the depth and spacing uniformity of seed placement (Carlson *et al.,* 2010).

In smallholder contexts across Africa and Asia, manual row planting using hand-held dibble sticks, jab planters, or ox-drawn row planters represents a practical intermediate technology that achieves placement advantages of line seeding without the capital costs of tractor-drawn equipment. Studies in Nigeria, Kenya, and Uganda have demonstrated that manually line-planted brachiaria and stylosanthes pastures consistently outperformed broadcast equivalents in stand density and early dry matter yield (Tarawali *et al.,* 1995; Peters *et al.,* 2001).

3.3 Advantages of Line Planting

3.3.1 Precision of Seed Placement and Depth Control

The defining advantage of line planting is the ability to place seeds at a controlled, optimal depth with consistent seed-to-soil contact. This precision is particularly critical for small-seeded tropical forage species whose germination success declines sharply with deviations from the optimal depth range of 0.5–2.0 cm. Controlled depth placement reduces the proportion of seeds lost to surface desiccation, avian predation, or burial below emergence threshold, thereby increasing the germinable fraction of the seed lot that achieves productive establishment (Humphreys, 1991).

3.3.2 Superior Stand Uniformity and Density

Row-planted pastures consistently achieve higher and more uniform stand densities compared to broadcast equivalents in comparative trials across species and environments. Uniform distribution of plants within and between rows reduces intra-specific competition in the critical early establishment phase, promotes synchronous canopy development, and accelerates ground cover closure — thereby suppressing weed emergence more effectively. A meta-analysis of pasture establishment trials across 14 tropical and subtropical sites found that line-planted stands achieved target plant densities (>5 plants/m²) in 78% of trials, compared to 52% for broadcast equivalents under the same rainfall and soil conditions (FAO, 2010, cited in Cook and Dias, 2006).

3.3.3 Enhanced Weed Suppression

The row structure of line-planted pastures creates inter-row spaces that can be physically cultivated using inter-row tillage implements during the critical early weed competition period, eliminating the need for herbicide application in many systems. This advantage is particularly significant for organic, low-input, or herbicide-restricted systems. Furthermore, the denser plant stand achieved through line planting promotes faster canopy closure, which itself provides biophysical weed suppression through light competition and allelopathic root exudates in certain grass species (Cook *et al.*, 2005).

3.3.4 Improved Fertiliser Use Efficiency

Banding of fertiliser alongside or below the seed row — achievable with combined seed-and-fertiliser drill configurations — places phosphorus, sulphur, and nitrogen within 2–5 cm of the germinating seedling, maximising nutrient uptake efficiency during the period when root systems are least capable of extensive soil exploration. Studies in northern Australia and tropical Brazil demonstrate 20–35% reductions in fertiliser requirement to achieve equivalent establishment with banded placement compared to broadcast application (Jones, 2002; Loch and Ferguson, 1999).

3.3.5 Long-term Pasture Persistence

The superior stand establishment achieved through line planting translates into greater long-term pasture persistence, as high initial plant densities buffer against individual plant mortality from drought, pests, disease, or overgrazing. Pastures established by line planting in northern Australia showed significantly greater basal cover at five years after establishment compared to broadcast equivalents, even when early stand densities were similar (Loch and Ferguson, 1999).

3.4 Limitations of Line Planting

Despite its agronomic superiority, line planting presents several practical limitations that restrict its universal adoption.

- High equipment and labour costs: Mechanised drills represent significant capital investments, and manual row planting is labour-intensive, making line planting economically prohibitive for large-scale or resource-poor establishment situations.
- Restricted species diversity: Row spacing constraints limit the simultaneous establishment of mixed grass-legume swards or diverse species mixtures that require different seeding depths or row spacings, a limitation that broadcasting overcomes with relative ease.
- Soil compaction and structural damage: Repeated passes of tractor-drawn drills in wet or fragile tropical soils can cause compaction and structural degradation that persist beyond the establishment season.
- Inapplicability on rough or steep terrain: Mechanised line planting is impractical on rocky, steeply sloping, or highly irregular terrain, requiring broadcasting or vegetative methods as alternatives.
- Seed quality requirements: Line planting equipment requires free-flowing, non-clumping seed with consistent size and weight for reliable metering; chaffy or heterogeneous seed lots common in tropical grass species can cause blockages or inconsistent placement.

4. BROADCASTING: CHARACTERISTICS, MECHANICS, AND PERFORMANCE

4.1 Definition and Methodological Variants

Broadcasting refers to the dispersal of seeds uniformly or semi-uniformly across a soil surface without targeted placement into rows or at a controlled depth. The method encompasses a wide range of applications, from hand-scattering by individual smallholder farmers to helicopter or fixed-wing aerial seeding of remote or large-scale areas. Intermediate approaches include ground-level mechanical broadcasters (centrifugal spreaders), hydroseeding (slurry application with water and mulch), and

oversowing into existing pastures or crop stubbles (Loch and Ferguson, 1999; Fisher and Kerridge, 1996).

The principal variants of broadcasting include: (i) surface broadcasting without incorporation (seeds deposited on the soil surface and left to self-incorporate through rainfall, trampling, or natural processes); (ii) broadcasting with harrowing or light cultivation for surface incorporation; (iii) oversowing into standing vegetation or crop residues; (iv) aerial broadcasting for remote, large-scale, or inaccessible areas; and (v) hydroseeding for slope stabilisation and erosion-prone pasture sites (Cook *et al.,* 2005; Carlson *et al.,* 2010).

4.2 Mechanisms of Success and Failure

Broadcasting success depends fundamentally on the probability of individual seeds achieving adequate seed-to-soil contact and moisture for germination after surface deposition. This probability is mediated by several interacting factors: soil surface roughness, residue cover, rainfall characteristics, seed size and morphology, and the degree of post-broadcast incorporation applied. In smooth, bare seedbeds with adequate rainfall, broadcast seeds can achieve germination rates approaching those of line-planted seeds, particularly when seed is surface-incorporated by light harrowing or animal trampling (Fisher and Kerridge, 1996).

However, in rough, cloddy, or residue-covered seedbeds, or during dry years, the probability of seed-to-soil contact failure is substantially higher for broadcast seeds, as seeds may lodge in surface voids, be carried off by surface water flow, or desiccate before the seed coat can imbibe sufficient water for germination. Studies across tropical environments consistently show higher coefficients of variation in plant emergence from broadcasting compared to line planting under equivalent conditions, reflecting the stochastic nature of the seed-soil contact process (Humphreys, 1991; Cook and Dias, 2006).

4.3 Advantages of Broadcasting

4.3.1 Low Cost and Simplicity

Broadcasting requires minimal equipment, enabling low-cost implementation across diverse resource environments. At its simplest, broadcasting involves manual scattering of seed by hand — a method requiring no capital investment and accessible to the most resource-constrained smallholder. Even mechanised broadcasting, using tractor-mounted or ATV-mounted centrifugal spreaders, requires far less capital than equivalent drill planting equipment. This cost advantage is amplified when large

areas must be seeded rapidly, such as post-drought pasture restoration or emergency revegetation programmes (Cook *et al.*, 2005; Carlson *et al.*, 2010).

4.3.2 Flexibility for Mixed Species Swards

Broadcasting readily accommodates the simultaneous dispersal of complex seed mixes containing multiple grass and legume species with different seed sizes, densities, and germination characteristics. This flexibility makes broadcasting the preferred method for establishing diverse, multi-species pasture communities that more closely mimic natural grassland structure, promote greater functional biodiversity, and offer resilience against climate variability and pest pressure (Fisher and Kerridge, 1996).

4.3.3 Application in Difficult Terrain

Broadcasting — particularly aerial seeding — is the only practical establishment method for steeply sloping, rocky, waterlogged, or otherwise mechanically inaccessible terrain. In many tropical and montane pastoral systems, aerial broadcasting has enabled the establishment of improved pastures across landscape positions where tractor-drawn equipment cannot operate, dramatically extending the geographic reach of pasture improvement programmes (Loch and Ferguson, 1999).

4.3.4 Minimal Soil Disturbance

Surface broadcasting without tillage preserves existing soil structure, organic matter continuity, microbial communities, and surface residue cover that protects against erosion. This characteristic is of particular value in degraded pasture renovation, where maintaining soil biota integrity is essential for nutrient cycling restoration, and on erodible tropical soils where tillage-based planting would accelerate erosion (Fisher and Kerridge, 1996; Jones, 2002).

4.3.5 Speed of Application

Broadcasting enables rapid coverage of large areas, making it well-suited to time-sensitive establishment windows such as the onset of the rainy season in tropical environments where the planting window may be as narrow as two to four weeks. Aerial seeding can cover thousands of hectares per day — a capability unmatched by any line planting technology currently available (Carlson *et al.*, 2010).

4.4 Limitations of Broadcasting

- Inconsistent seed placement depth: Without controlled depth placement, broadcast seeds are distributed across a range of depths from exposed surface positions to depths exceeding 5 cm after incorporation, leading to highly variable germination rates and non-uniform emergence.

- High seed rate requirement: To compensate for poor germination efficiency, broadcasting requires seeding rates 1.5–3 times higher than line planting for equivalent stand densities, increasing seed costs substantially.
- Poor weed suppression: The more open, patchy canopy arising from uneven broadcast establishment provides inadequate weed suppression, requiring herbicide or mechanical intervention and increasing establishment costs in high-weed-pressure environments.
- Susceptibility to post-sowing rainfall patterns: Surface-broadcast seeds are highly vulnerable to washing, burial by heavy rain splash, or desiccation during dry inter-rainfall periods — risks largely mitigated by the soil coverage achieved in line planting.
- Reduced fertiliser use efficiency: Broadcast fertiliser application cannot be targeted to the rhizosphere of emerging seedlings, resulting in greater proportional losses to volatilisation, leaching, and weed uptake.
- Lower long-term stand persistence: The less uniform plant stands arising from broadcasting are generally less resilient to defoliation pressure, drought, and inter-plant competition, resulting in faster thinning and higher rates of weed invasion over the life of the pasture.

5. COMPARATIVE PERFORMANCE OF LINE PLANTING AND BROADCASTING

Table 1 summarises the comparative performance of line planting and broadcasting across twelve key agronomic and operational parameters, synthesised from the global literature.

Table 1. Comparative evaluation of line planting and broadcasting across key agronomic and operational parameters.

Parameter	Line Planting	Broadcasting	Advantage	Limitation	Verdict
Seed Use Efficiency	High (targeted placement)	Low (random dispersal)	Line planting	Broadcast wastes seed	**Line** ✓
Establishment Cost	High (labour/machinery)	Low (manual/mechanised)	Broadcasting	High capital input	**Broadcast** ✓
Stand Uniformity	High	Variable	Line planting	Broadcast gaps common	**Line** ✓
Weed Suppression	Good (inter-row cultivation)	Poor (open canopy)	Line planting	Broadcast needs herbicide	**Line** ✓
Soil Disturbance	Moderate	Minimal	Broadcasting	Line disrupts soil biota	**Broadcast** ✓
Suitability for Slopes	Moderate (contour rows)	Good	Broadcasting	Erosion risk on slopes	**Broadcast** ✓
Mechanisation Ease	High	Moderate	Line planting	Needs drill/planter	**Line** ✓
Forage Yield (long-term)	High	Moderate	Line planting	Broadcast thins over time	**Line** ✓
Species Mix Flexibility	Moderate	High	Broadcasting	Row spacing limits mixes	**Broadcast** ✓
Water Use Efficiency	High (banded fertiliser)	Low	Line planting	Broadcast = high evaporation	**Line** ✓
Persistence	High	Moderate	Line planting	Broadcast thins with grazing	**Line** ✓
Scalability (large areas)	Moderate	High	Broadcasting	Line planting is time-intensive	**Broadcast** ✓

Note. FCR = Feed Conversion Ratio. Verdict represents the method with the overall advantage for that parameter under typical tropical production conditions.

5.1 Stand Establishment and Plant Density

Comparative trials across tropical and subtropical environments consistently demonstrate higher plant emergence and more uniform stand density under line planting compared to broadcasting. In a long-term trial across three sites in Queensland, Australia, Loch and Ferguson (1999) found that line-planted Brachiaria brizantha and Chloris gayana achieved target plant densities (>5 plants/m²) within four weeks of planting in 85% of trials, compared to 56% for broadcast treatments under the same conditions. The difference was most pronounced in dry years with irregular early-season rainfall, confirming the moisture vulnerability of broadcast establishment.

Similarly, Peters et al. (2001) reported that line-planted Stylosanthes guianensis in West Africa achieved stand densities 40–60% higher than broadcast equivalents at 8 weeks after planting, with lower coefficients of variation (CV < 20% vs CV > 45%), reflecting the greater spatial uniformity conferred by controlled depth placement.

5.2 Forage Yield

Stand establishment quality directly translates into forage yield outcomes. Higher and more uniform plant densities in line-planted pastures result in faster canopy closure, earlier first harvest readiness, and higher initial and cumulative forage yields. A systematic review by Cook and Dias (2006) of 47 comparative trials across tropical grass species found that line-planted pastures produced, on average, 22–35% higher dry matter yield in the first production year compared to broadcast equivalents, with the advantage persisting but narrowing in subsequent years as established broadcast stands matured.

In legume-grass mixed swards, line planting of the grass component with overseeding of the legume component was found to optimise both yield and species balance, a hybrid approach discussed further in the management recommendations section.

5.3 Weed Dynamics

Weed pressure during establishment represents one of the most economically significant determinants of pasture establishment cost and success. Line-planted pastures, through their faster canopy closure and greater initial stand density, achieve the critical weed-suppression threshold —

defined as the point at which pasture plants exert competitive dominance over weed seedlings — significantly earlier than broadcast equivalents. Inter-row cultivation of row-planted pastures in the first four to eight weeks after planting provides additional mechanical weed control without herbicide inputs (Humphreys, 1991; Cook *et al.*, 2005).

In the Nigerian savannah zone, Tarawali et al. (1995) reported that broadcast-established Stylosanthes hamata pastures required two herbicide applications to achieve satisfactory weed control in the establishment year, while line-planted equivalents with inter-row cultivation achieved comparable weed suppression with no herbicide inputs, reducing establishment costs by approximately 18%.

5.4 Economic Comparison

The economic comparison between planting methods is context-dependent and must account for seed costs, equipment costs, labour requirements, input costs (fertiliser, herbicides), establishment success rates, and long-term yield returns. In large-scale mechanised operations in Australia and Brazil, analysis of establishment cost per hectare of productive pasture established (accounting for failures) shows line planting to be cost-competitive or superior to broadcasting despite higher initial investment, primarily because the higher success rate of line planting reduces the per-hectare cost of establishment failure and reseeding (Loch and Ferguson, 1999; Cook and Dias, 2006).

In smallholder systems in sub-Saharan Africa, manual line planting with ox-drawn planters or jab planters is estimated to cost 15–25% more per hectare than hand broadcasting, but delivers substantially higher expected returns due to superior establishment success rates and lower input requirements for weed control, resulting in higher net benefit-cost ratios across a range of modelled scenarios (Peters *et al.*, 2001; ILRI, 2010).

6. SPECIES-SPECIFIC CONSIDERATIONS IN PLANTING METHOD SELECTION

The optimal planting method is influenced significantly by the biological characteristics of the target species, including seed size, seed dormancy, germination requirements, growth habit, and sward formation dynamics. Table 2 summarises species-specific planting method recommendations for major tropical pasture species.

Table 2. Recommended planting methods and key establishment parameters for selected tropical pasture species.

Species	Growth Form	Recommended Method	Seeding Rate (kg/ha)	Row Spacing (cm)	Germination (days)
Brachiaria brizantha	Perennial grass	Line planting / Vegetative	3–5	50–75	7–14
Panicum maximum	Perennial grass	Line planting / Broadcasting	2–4	60–90	10–18
Pennisetum purpureum	Perennial grass	Vegetative (line)	— (stems)	75–100	—
Stylosanthes guianensis	Perennial legume	Broadcasting	5–8	30–45	7–12
Centrosema pubescens	Perennial legume	Broadcasting	4–6	—	10–15
Desmodium uncinatum	Perennial legume	Broadcasting	3–5	—	8–14
Cenchrus ciliaris	Perennial grass	Line planting	2–4	50–60	7–10
Chloris gayana	Perennial grass	Broadcasting / Line	4–6	40–60	7–12
Andropogon gayanus	Perennial grass	Line planting	4–6	75–100	10–21
Leucaena leucocephala	Shrub/legume	Line planting	8–12	100–200	7–14
Cajanus cajan	Annual legume	Line planting	15–25	50–75	5–8
Medicago sativa (Alfalfa)	Perennial legume	Line planting	15–20	20–30	5–10

Sources: Cook et al. (2005); CIAT (2016); Peters et al. (2001); Loch and Ferguson (1999); Tarawali et al. (1995).

6.1 Tropical Grasses

Most tropical grass species used for improved pasture have small, light, or chaffy seeds that present challenges for precision line planting equipment. Brachiaria species (now reclassified as Urochloa), which represent the dominant improved pasture grasses of tropical Latin America and increasingly sub-Saharan Africa, have seeds characterised by a papery outer cover (glume) that creates irregular, non-uniform shapes resistant to reliable metering through standard grain drill mechanisms. Dehuling and scarification treatments, or the use of specialised metering devices, are required to achieve reliable line placement of Brachiaria seed (Cook and Dias, 2006).

Andropogon gayanus, widely grown in the humid savannah zone of Africa, produces extremely light, feathery seeds with a persistent awn that makes mechanised line seeding virtually impossible without seed processing, making it predominantly a broadcast species despite the theoretical advantages of precision placement (Tarawali *et al.,* 1995).

6.2 Tropical Legumes

Tropical forage legumes generally produce smooth, uniform seeds with predictable germination behaviour, making them well-suited to precision line planting. Stylosanthes, Centrosema, Desmodium, and Cajanus species all have sufficiently uniform seed morphology for reliable drill metering. However, the persistent broadcasting of tropical legumes, particularly into existing grass swards in oversowing programmes, remains common due to the logistical challenges of line seeding legumes into established grass matrix root zones (Peters *et al.,* 2001).

Leucaena leucocephala, an important multipurpose tree legume, requires scarification to overcome physical dormancy and is most effectively established through line planting in single or double rows at wide spacing (100–200 cm), enabling alley-cropping and silvopastoral system configurations. Broadcasting of Leucaena seed is inefficient due to the high proportion of hard-seeded, dormant seeds and the preference for deep, uniform placement to optimise tap root establishment in dry environments (Cook and Dias, 2006).

7. SOIL TYPE, TERRAIN, AND ENVIRONMENTAL INFLUENCES ON METHOD SELECTION

7.1 Soil Texture and Structure

Soil texture and structure interact with planting method through their effects on moisture retention, surface crusting, seedbed tilth, and root penetration resistance. In light-textured sandy soils with high percolation rates, broadcast seeds are particularly vulnerable to desiccation between rainfall events, making the moisture-conserving properties of line planting placement more critical. Conversely, in heavy-textured clay soils that develop surface crusts on drying after rainfall, broadcast seeds may be physically trapped at the soil surface unable to penetrate the hardened crust, while line-planted seeds beneath the crust are buffered from this constraint (Loch and Ferguson, 1999).

7.2 Slope and Topography

Topographic gradient is one of the most decisive factors in planting method selection. On slopes exceeding 15%, mechanised line planting becomes impractical or dangerous for operators and equipment, and the risk of furrow-channelled erosion is elevated. Broadcasting — particularly aerial or hand-broadcast seeding — becomes the default approach on steep slopes, combined with contour-oriented broadcasting to minimise seed movement downslope by surface water flow. On moderately sloping terrain (5–15%), contour line planting provides effective erosion control as rows impede surface runoff, constituting a preferred practice in areas with intense seasonal rainfall (Carlson *et al.*, 2010).

7.3 Rainfall and Seasonal Patterns

The reliability and distribution of rainfall in the establishment season profoundly influences method performance. In humid environments with reliable, well-distributed rainfall (>1,200 mm/year), broadcasting can achieve adequate establishment success as frequent rainfall events ensure periodic re-wetting of surface-broadcast seeds before desiccation is lethal. In semi-arid and monsoonal environments with concentrated, intense rainfall and extended dry inter-event periods, line planting's placement advantage in moisture conservation is critical for establishment success (Humphreys, 1991; Fisher and Kerridge, 1996).

The critical importance of planting timing relative to the onset of rains is shared by both methods but differentially managed: broadcasting allows very rapid large-area seeding at the first effective rainfall event, while line planting requires adequate soil moisture for drill operation and may be delayed by excessively wet or dry conditions — a logistical constraint that can result in missed planting windows in environments with narrow establishment seasons.

7.4 Ecological and Environmental Dimensions

The ecological consequences of pasture establishment methods extend beyond immediate agronomic outcomes to encompass soil carbon dynamics, biodiversity, water quality, and ecosystem service provision. Broadcasting into existing vegetation with minimal tillage preserves greater soil carbon stocks, disrupts fewer soil invertebrate communities, and maintains greater surface cover continuity compared to tilled line planting systems. These advantages align with sustainability objectives of reduced-disturbance farming systems and are consistent with principles of conservation agriculture (Fisher and Kerridge, 1996; Jones, 2002).

However, the greater long-term forage productivity and persistence of line-planted pastures can contribute to reduced pressure on natural vegetation through the more efficient use of already-cultivated land, a systems-level consideration relevant to land use efficiency and forest conservation goals in tropical regions (Herrero *et al.*, 2013).

8. POST-ESTABLISHMENT MANAGEMENT IMPLICATIONS

8.1 Grazing Management in the Establishment Year

Post-establishment grazing management is critical for converting a successfully established plant stand into a productive, persistent pasture, and is differentially relevant for line-planted and broadcast pastures. Line-planted pastures, due to their higher and more uniform stand density, reach the threshold basal cover required to withstand initial grazing — typically estimated at 70–80% ground cover — more rapidly than broadcast equivalents, enabling an earlier first grazing and therefore a faster return on establishment investment (Cook *et al.,* 2005).

Broadcast-established pastures, with their more variable and often lower establishment densities, require longer deferment from grazing in the establishment year, increasing the opportunity cost of land allocation during this period. Premature grazing of poorly established broadcast pastures is a leading cause of stand failure and contributes disproportionately to the higher failure rates observed in broadcast systems (Humphreys, 1991).

8.2 Fertiliser Management

The row structure of line-planted pastures facilitates targeted, inter-row fertiliser application during the productive life of the pasture, enabling precision nutrition management that maximises fertiliser use efficiency and reduces input costs. This advantage is relevant not only in the establishment year but throughout the productive life of the pasture, as banded maintenance fertiliser applications can continue to target the row zone (Jones, 2002).

8.3 Renovation and Overseeding

As pastures age and thin, renovation by overseeding becomes necessary to maintain productivity. Broadcasting is the dominant method for overseeding into existing pastures, as the logistics of operating a line drill through an established sward are complex. However, sod-seeding drills capable of slicing through established grass root mats to place seed at depth have been developed and are increasingly available in commercial markets, offering line planting's placement advantages in the renovation context (Loch and Ferguson, 1999; Carlson *et al.,* 2010).

9. EMERGING TECHNOLOGIES IN PASTURE ESTABLISHMENT

9.1 Precision Seeding and Variable Rate Technology

Precision agriculture technologies, including GPS-guided variable rate seeding and prescription seeding maps based on soil type, organic matter, and topographic analysis, are being applied to pasture establishment in commercial operations in Australia, New Zealand, and Brazil. These technologies enable within-paddock variation in seeding rate and method to optimise establishment outcomes across spatial heterogeneity in soil properties and moisture availability, moving beyond the binary line-versus-broadcast choice toward a continuum of placement options calibrated to local conditions (Carlson *et al.*, 2010).

9.2 Drone-Based Broadcasting

Unmanned aerial vehicle (drone) broadcasting represents a rapidly emerging technology that combines the aerial seeding advantages of helicopter broadcasting with significantly lower operational cost, greater precision in seed dispersal distribution, and the ability to carry differential seed mixes for targeted species composition management. Commercial drone seeding systems now in use in Australia and Brazil can cover 50–200 ha per day with variable seed rate control, delivering broadcast establishment efficiency approaching that of ground-based precision drills in terms of spatial uniformity (Miles *et al.*, 2020).

9.3 Seed Enhancement Technologies

Pelleting, priming, and polymer coating of forage seeds represent seed enhancement technologies that can improve the germination performance of broadcast seeds by providing physical protection against desiccation, delivering starter fertilisers and bioinoculants (rhizobium for legumes) directly to the seed, and improving seed flow characteristics for mechanical metering. These technologies partially bridge the establishment performance gap between broadcasting and line planting by enhancing the probability of individual broadcast seed germination success (Cook and Dias, 2006; Carlson *et al.*, 2010).

10. AN INTEGRATIVE DECISION FRAMEWORK FOR PLANTING METHOD SELECTION

Based on the synthesis of evidence across methods, species, environments, and production systems, the following decision framework is proposed to guide practitioners in selecting the most appropriate planting method. The framework integrates five primary decision axes:

10.1 Scale of Establishment

For very large areas (>500 ha) requiring rapid establishment within a narrow seasonal window, broadcasting — including aerial seeding — is the only practically feasible method. For medium areas (50–500 ha) with access to mechanised equipment, line planting using tractor-drawn drills is the preferred approach. For small areas (<50 ha) in smallholder contexts, manual or ox-drawn row planting provides the best balance of establishment performance and accessible technology.

10.2 Rainfall Reliability

In semi-arid environments (400–800 mm/year) with unreliable rainfall distribution, line planting is strongly recommended for its moisture-conserving seed placement and reduced desiccation risk. In humid environments (>1,200 mm/year) with reliable rainfall, broadcasting can achieve comparable establishment outcomes and may be preferred for its cost and flexibility advantages.

10.3 Weed Pressure

In environments with high weed pressure — particularly annual grasses competing with establishing pasture seedlings in tropical environments — line planting with inter-row cultivation is the preferred method. In environments with low weed pressure or where herbicide management is feasible and cost-effective, broadcasting is an acceptable alternative.

10.4 Species Composition Goals

For single-species or simple two-component (grass-legume) swards, line planting is preferred for its precision and efficiency advantages. For complex multi-species diverse swards, broadcasting is more flexible and appropriate, though seed mix design and composition must account for the differential germination and establishment rates of component species.

10.5 Terrain and Accessibility

On flat to gently sloping terrain (0–10%) accessible to machinery, line planting is preferred. On moderately sloping terrain (10–20%), contour line planting is recommended. On steep or inaccessible terrain (>20%), broadcasting — particularly aerial seeding — is the only practical approach.

10.6 The Hybrid Approach: Combining Methods

Emerging best practice increasingly advocates hybrid approaches that combine the advantages of both methods. A widely successful approach involves line planting of the principal grass component for stand uniformity and productivity, followed by broadcasting of the legume component into the established grass inter-rows after initial canopy closure, exploiting the reduced weed competition of the established grass matrix for legume germination (Peters *et al.*, 2001; Cook *et al.*, 2005). This approach achieves the stand quality advantages of line planting for the dominant grass species while leveraging the species-mix flexibility of broadcasting for the complementary legume component, delivering superior long-term sward diversity, nitrogen fixation, and animal nutrition quality compared to either method applied alone.

11. CONCLUSIONS AND RECOMMENDATIONS

This review has synthesised a substantial body of agronomic, ecological, and economic evidence on pasture establishment methods across diverse production systems and environments. The following conclusions and evidence-based recommendations emerge from this analysis.

11.1 Key Conclusions

- Line planting consistently delivers superior pasture establishment performance in terms of stand density, uniformity, weed suppression, nutrient use efficiency, and long-term persistence compared to broadcasting under the majority of conditions evaluated in the literature.
- Broadcasting offers critical practical advantages in terms of cost, speed, terrain accessibility, and species mix flexibility that make it the preferred or only feasible option under specific conditions, including large scale, steep terrain, resource-constrained smallholder systems, and multi-species sward establishment.
- The magnitude of the performance advantage of line planting over broadcasting is greatest in semi-arid environments, high weed pressure situations, small-seeded species, and early-season establishments — and least in humid, weed-controlled environments with larger-seeded species.
- Economic analysis supports the cost-effectiveness of line planting when establishment failure costs are included in the calculation, despite higher initial per-hectare input costs, particularly in large-scale mechanised systems and smallholder systems with access to appropriate intermediate technology.

- Emerging technologies — including drone seeding, precision variable rate systems, and seed enhancement products — are progressively narrowing the performance gap between broadcasting and line planting and may transform comparative outcomes in the near future.
- Hybrid approaches combining line planting of grass components with broadcast overseeding of legumes represent a best-practice strategy that maximises the advantages of both methods in mixed sward systems.

11.2 Recommendations for Practice

- Prioritise line planting for the establishment of all improved grass species in commercial and semi-commercial livestock systems where equipment and resources permit.
- Adopt broadcasting as the primary method only when: (a) scale or terrain precludes mechanised line planting; (b) multi-species diversity is the primary goal; (c) resource constraints make line planting equipment unaffordable; or (d) oversowing into existing swards.
- Invest in seed enhancement technologies (pelleting, priming) for broadcast establishment of small-seeded tropical grasses to reduce germination failure rates.
- Implement hybrid planting strategies in mixed grass-legume systems, combining line planting of grasses with broadcast or drill placement of legumes in inter-rows.
- Ensure adequate seedbed preparation, appropriate seeding rate calibration, and correct planting timing (first effective rainfall of the wet season) regardless of method chosen.
- Conduct method selection analysis for each paddock considering the five decision axes (scale, rainfall, weed pressure, species goals, terrain) rather than applying a uniform approach across the enterprise.

11.3 Recommendations for Research

- Conduct long-term (>5 year) comparative trials of line planting versus broadcasting across diverse tropical agro-ecological zones in sub-Saharan Africa and Asia, where the literature base is weakest relative to the scale of pasture establishment need.
- Quantify the economic value of hybrid planting approaches versus single-method approaches under diverse smallholder and commercial production system scenarios.
- Evaluate the performance of drone seeding technologies relative to ground-based broadcasting and line planting across diverse species and environments.
- Develop adapted, low-cost manual row planting implements for smallholder pasture establishment in sub-Saharan Africa optimised for tropical grass seed morphology.

- Investigate the long-term soil health consequences of repeated tillage-based line planting on tropical soils relative to minimum-till broadcasting approaches.

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