In forage-based production systems farmers are frequently confronted with a decision of when, or whether, to reseed pasture in order to maintain or improve productivity. At its simplest such a decision would be guided by evaluation of the costs of improvement in relation to the benefits accruing from the newly-sown pasture but, in practice, costs may be difficult to define. In addition to labor, equipment, and material costs of the field operations necessary for planting, there are less obvious costs that result from production losses during the period of ground preparation and establishment of a new crop. While it is generally assumed that these production losses may be compensated over time by increased productivity in a reseeded pasture, the period of amortization may be prolonged (75,80). Hopkins et al. (51) found that yield benefits deriving from reseeded compared with continuous pasture were largely eliminated when establishment-year production shortfall of the reseed was considered. Lack of persistence, slow establishment of reseeds, and periodic stand failure will further compromise the long-term productivity of reseeded pastures and the economic viability of a reseeding program (6,9,77).

Much has been published on the effectiveness of seeding by minimal-tillage methods, but the focus of work has been on minimal tillage as an alternative to conventional cultivation and sowing for establishment of annual crops (67). Less attention has been given to its impact on pastures or on its value in low-input pasture systems, where resource constraints make reduced cultivation and infrequent reseeding especially desirable. Seeding pasture by minimal tillage offers several potential advantages over conventional methods, including cost savings resulting from reduced cultivation, reduced risk of soil erosion, improved trafficability of land, and reduced damage by grazing animals (67). However, the potential of minimal tillage to reduce establishment-phase production loss by minimizing damage to existing pasture has not been specifically addressed. Nor is it clear whether the savings in cultivation and planting effort that use of minimal tillage permits are offset by longer-term impacts of reduced pasture productivity, reduced persistence and a need for more frequent pasture renewal. This literature review assesses the value of minimum tillage for pasture improvement and its particular application in low-input systems.

Presentation of data. For comparison of performance parameters (emergence or yield), "minimal tillage" has been interpreted to mean seeding by no-till or conventional drill into ground undisturbed except for the passage of the seeder, or by broadcasting onto untilled or frost-tilled ground [pre-plant tillage 0 to 3 on the 0 to 10 scale used by Wolf et al., (95)]. Data sources were selected to provide direct comparison between minimal tillage and conventional seeding practices, and parameter values have been expressed as a percentage of no-till drill values (= 100) unless otherwise noted, to allow comparison among disparate experiments and crop types. Four main categories of minimal-tillage seeding were identified: cool-season grass sown into cool-season grass (CSG-CSG); cool-season grass sown into warm-season grass (CSG-WSG); cool-season legume sown into cool-season grass (CSL-CSG); and cool-season legume sown into warm-season grass (CSL-WSG). Some instances of cool-season grass sown
into cool-season legume (CSG-CSL); cool-season legume sown into cool-season legume (CSL-CSL); and warm-season grass sown into cool-season grass (WSG-CSG) have also been reported and are included in figures.

**Effects of Minimal-Tillage Practices on Pasture Plant Emergence**

Broadcast seeding generally results in the lowest seedling emergence of forage species, and drilling into cultivated ground produces slightly greater emergence than minimal-tillage seeding (Fig. 1). Among a range of planting practices, the use of herbicide application to kill or suppress existing pasture has the greatest influence on emergence success of forages seeded using minimal-tillage methods (Fig. 2), and glyphosate [N-(phosphonomethyl) glycine] or paraquat (1,1’-dimethyl-4,4’bipyridinium) are the herbicides most commonly used for suppression or destruction of existing pasture. Generally glyphosate was more effective than paraquat and applications 14 to 30 days prior to planting were more effective than those made within a week before planting, or post-planting (27,62,93). Emergence of crops sown by minimal tillage into pasture without prior herbicide application averaged 66% of that obtained when minimal-tillage seeding was preceded by herbicide application, when the most effective herbicide treatments were considered (Fig. 2). Effects of timing and rate of herbicide application are expressed through their effectiveness in controlling resident crop growth and cover, and therefore the competitive environment for an introduced crop. Although variable, the response to herbicide appears to be greater with cool-season crops sown into cool-season crops (where emergence without herbicide application to existing pasture averaged 53% of that obtained when herbicide is used), than with cool-season sown into warm season crops, in which emergence without herbicide averaged 69% of emergence with herbicide (Fig. 2).

**Fig. 1. Effect of sowing method on relative emergence of forages.**

- **Category**: Sown crop × Resident crop
- **Relative emergence of forages sown broadcast or drilled following cultivation, compared with minimal tillage (=100)**
- **Seeding Count**: Stage, Method, Source, Reference
- **Legend**: Green = Broadcast, Yellow = Cultivate + drill

<table>
<thead>
<tr>
<th>Category</th>
<th>Sown crop × Resident crop</th>
<th>Seedling emergence (%)</th>
<th>Seeding Count</th>
<th>Source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSG-WSG</td>
<td></td>
<td>80</td>
<td>&gt;160 DAS SR</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>CSL-WSG</td>
<td></td>
<td>70</td>
<td>42 DAS PD</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>CSL-SLG</td>
<td></td>
<td>45</td>
<td>Unsp PE SR</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>CSL-WSG</td>
<td></td>
<td>20</td>
<td>12-21 DAS PD</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>CSL-SLG</td>
<td></td>
<td>30</td>
<td>14-28 DAS PD</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>CSL-SLG</td>
<td></td>
<td>29</td>
<td>50 DAS PD</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>CSL-CSL</td>
<td></td>
<td>39</td>
<td>42 DAS PD</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>CSG-CSL</td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

x CSG = cool-season grass; CSL = cool-season legume; WSG = warm-season grass; WSL = warm-season legume.

y Drilled treatments except for (4) = Broadcast treatments, where minimal-tillage broadcast = 100.

z PE = percentage emergence; emerged seedlings expressed as a % of viable seed sown per unit area, PD = plant density; number of emerged seedlings per unit area, SR = stand rating; presence of sown species within a grid, DAS = Days after sowing, DAE = Days after emergence, Unsp = Not specified.
Suppression of competition from a growing resident crop generally improves the establishment and productivity of a new seeding. In contrast, the effects of cover from resident crop residues are more variable; residues may reduce early-season soil temperatures and limit early growth of introduced species, but can reduce soil moisture loss and protect seedlings from warm and cool season temperature extremes (16,32,96). The accumulation of excess crop residues as trash on drilling equipment may reduce the effectiveness of sowing by preventing uniform seed placement or by reducing good seed-soil contact (67,79). Close defoliation or burning can be used as alternatives to herbicide to manipulate cover and competition, but may be of limited efficacy; close-grazing was found to be of limited value (73) and burning was not effective in control of tall fescue (*Festuca arundinacea* Schreb.) (92). Butler et al. (14) found that, for establishment of ryegrass or clover, burning of broomsedge (*Andropogon virginicus* L.) after frost was less effective than paraquat treatment followed by burning, however they did observe that the ash left after burning provided a satisfactory seedbed for small seeds.

**Soil bulk density effects.** Soil bulk density effects on pasture establishment specifically linked to the use of minimal tillage have not been identified, however, there is ample evidence that compaction of soil by field equipment (12,30,42) or by grazing animals (47,66) reduces plant growth and limits forage production. Increased soil bulk density reduced the rate of radicle-entry of surface-sown seeds (17) and decreased clover emergence by up to 32% with planting at a depth of 0.6 inches, but had only limited impact on emergence of tall fescue planted at the same depth (21).

**Pest and disease problems at establishment.** Predation by a range of insect (15,74,98) or mollusk (5,15,33,57,93,98) pests may result in less effective establishment and reduced yield of newly-sown forages. This damage may be more acute in crops sown by minimal tillage than with conventional cultivation (33,57,74,94), however, Ellis et al. (36) noted that the incidence of damage by frit fly (*Oscinella frit* L.) was greater in conventional than in no-till seedings, and attributed this to a dilution of predator effect over both resident and establishing plants. Trimming, desiccation, or burning of crop residues associated with

<table>
<thead>
<tr>
<th>Category</th>
<th>Relative emergence of forages sown without herbicide suppression of existing pasture, compared with minimal-tillage seeding following herbicide use (=100)</th>
<th>Count method</th>
<th>Source Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSL-WSG</td>
<td>50</td>
<td>PE</td>
<td>38</td>
</tr>
<tr>
<td>CSL-WSG</td>
<td>93</td>
<td>PD</td>
<td>31</td>
</tr>
<tr>
<td>CSL-CSG</td>
<td>50</td>
<td>PD</td>
<td>97</td>
</tr>
<tr>
<td>CSL-CSG</td>
<td>29</td>
<td>PE</td>
<td>26</td>
</tr>
<tr>
<td>CSL-PE</td>
<td>29</td>
<td>PE</td>
<td>27</td>
</tr>
<tr>
<td>CSG-WSG</td>
<td>88</td>
<td>PD</td>
<td>42</td>
</tr>
<tr>
<td>CSG-WSD</td>
<td>88</td>
<td>PD</td>
<td>73</td>
</tr>
<tr>
<td>CSG-CGL</td>
<td>88</td>
<td>PD</td>
<td>10</td>
</tr>
<tr>
<td>CSG-CGL</td>
<td>88</td>
<td>PE</td>
<td>62</td>
</tr>
<tr>
<td>CSG-CGL</td>
<td>57</td>
<td>PE</td>
<td>19</td>
</tr>
<tr>
<td>CSG-CGL</td>
<td>73</td>
<td>PE</td>
<td>32</td>
</tr>
<tr>
<td>CSG-CGL</td>
<td>93</td>
<td>PE</td>
<td>76</td>
</tr>
</tbody>
</table>

X CSG = cool-season grass; CSL = cool-season legume; WSG = warm-season grass; WSL = warm-season legume.

Y Drilled treatments except for *x* = Broadcast treatments, where minimal-tillage broadcast = 100.

Z PE = percentage emergence; emerged seedlings expressed as a % of viable seed sown per unit area, PD = plant density; number of emerged seedlings per unit area, SR = stand rating; presence of sown species within a grid.

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minimal-tillage seeding will provide a less favorable environment for mollusks, and may enhance establishment (57,93). Fenner (39) observed that the vulnerability of seedlings to snail (Helix aspersa Müller) predation decreased rapidly with time and increase in seedling size; therefore conditions that slow seedling growth are likely to increase snail predation and reduce seedling survival. Legumes appear to be particularly vulnerable to mollusk damage when sown with minimal tillage (74) and are likely to be preferentially grazed in mixed pastures (5). Fungicidal seed dressing can increase establishment and early season yield of resown grasses (60) but there is little evidence of a difference in establishment response to fungicide use between seeds sown into cultivated ground and those sown by minimal tillage. Lewis (61) suggested that increased soil bulk density might reduce seedling growth rate and prolong the period of greatest risk for pathogen infection, and it could be inferred that reduced tillage would thus increase the risk of disease infection and reduce seedling establishment. The effectiveness of pesticide or fungicide in improving yield is variable, and depends on the extent of pest or disease challenge to the crop (5,54,97). Modification of planting dates to avoid periods of high pest population may be more effective than pesticide application in reducing the effects of predators (15,54,74).

**Allelopathic effects.** Several commonly-used forage species, including tall fescue, Italian ryegrass (Lolium multiflorum Lam.), perennial ryegrass (L. perenne L.), orchardgrass (Dactylis glomerata L.), alfalfa (Medicago sativa L.), and white clover (Trifolium repens L.) have been shown in bioassay studies (63,81,91) to exhibit allelopathic characteristics that may impact establishment success of minimal-tillage seeding. A specific and quantified impact of allelopathy in reducing establishment or productivity of overseeded field crops is not often reported with grasses, although Wardle et al. (91) showed close correlation between bioassay and field responses of an indicator plant (Carduus nutans L.) to a range of grassland species. There is, however, strong evidence of an allelopathic response in alfalfa, where autotoxicity may limit the success of efforts to renovate declining alfalfa stands by overseeding (50,55,63), unless a sufficient interval, ranging from 2 weeks (84) to 12 months (55), is allowed before planting the new crop.

**Forage Production and Persistence**

**Establishment period production losses.** Some production loss during establishment of a new pasture is almost inevitable, since both minimal-tillage and conventional planting methods result in damage to existing pasture through cultivation, or by herbicide treatment associated with minimal tillage (9,20,43,49,80,83,85). This transition loss can significantly reduce the longer-term benefit derived from reseeding of pasture (6,51,75,80). The importance of production loss associated with resowing pasture depends on the duration and seasonality of the transition from existing to renewed pasture, and therefore on the lost potential productivity of existing pasture during this period. Estimates of production loss during establishment of reseeded pasture are summarized in Table 1. The significance of transition loss is increased if a reseed fails to establish, as this will prolong the period of reduced productivity. Although authors (16,20,29) have commented that pasture re-seeding is a risky process, few estimates of the probability of reseed failure have been published. Crowley (23) reported a range of 7 to 34% failure with conventional tillage and planting techniques and Ries and Hofmann (72) observed 32 to 55% failure with direct seeding of a range of pasture grasses into stubble of wheat (Triticum aestivum L.).
Table 1. Estimates of forage yield reduction during the transition from existing to renewed pasture, associated with reseeding, cultivation, or suppression of existing pasture.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sowing technique</th>
<th>Establishment-period yield reduction (lb/acre)</th>
<th>Yield reduction % of untreated existing pasture</th>
<th>Source reference #</th>
</tr>
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<tbody>
<tr>
<td>Sown - Resident crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSG-CSG</td>
<td>CT</td>
<td>1090</td>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td>CSG-CSG</td>
<td>CT</td>
<td>2390</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>CSG-CSG</td>
<td>MT</td>
<td>560</td>
<td>84(^{b})</td>
<td>83</td>
</tr>
<tr>
<td>CSG-CSG</td>
<td>MT</td>
<td>880</td>
<td>33</td>
<td>49</td>
</tr>
<tr>
<td>CSL-CSG</td>
<td>MT</td>
<td>1300</td>
<td>70(^{a})</td>
<td>76</td>
</tr>
<tr>
<td>CSL-CSG</td>
<td>MT</td>
<td>210</td>
<td>16</td>
<td>65</td>
</tr>
<tr>
<td>CSL-CSG</td>
<td>MT</td>
<td>1210</td>
<td>87</td>
<td>97</td>
</tr>
</tbody>
</table>

x CSG = cool-season grass; CSL = cool-season legume; WSG = warm-season grass; WSL = warm-season legume.
y CT = conventional tillage; MT = minimal tillage.
z First growing season after sowing or, \(^{a}\)42 days after sowing, \(^{b}\)54 days after sowing.

Comparison of cumulative forage yields (seeding- and post-seeding-years) indicates that yields of forage sown conventionally are on average approximately 20% greater than those from crops established by minimal tillage. However, this comparison does not account for the impact of herbicide use on the effectiveness of minimal-tillage seeding. Forage yields of crops established by minimal tillage may be increased by averages of 36% (grasses) and 17% (legumes) when the most effective herbicide treatment in an experiment is compared with no-herbicide treatments (Fig. 3). In experiments where direct comparison of seeding method was made, the cumulative forage yields following conventional tillage were an average of 9.5% greater than those with minimal tillage + herbicide treatment (Fig. 4). Since cumulative forage yields were generally greater with cultivated and sown treatments, even when these were compared with the best minimal-tillage treatments, this suggests that any production losses during the establishment phase may be compensated by greater productivity of forages grown on tilled ground. However, there are no comparisons of forage yields in conventional and minimal-tillage seeding over multiple cycles of reseeding, so long-term productivity responses to seeding method cannot be evaluated directly.
Persistence of forages sown with minimal tillage. There are few direct comparisons of the change over time of plant density or forage yield in crops sown following minimal or conventional tillage. Bellotti et al. (10) and Samson and Moser (76) showed that within the first two years of introduction of new plants the decline in plant density in both no-till and cultivated crops was similar. Laidlaw (59) reported that, although the content of sown grass species in total DM declined during the five years following sowing, within years there was no difference in sown grass contents of plowed or minimal tillage (disked) treatments. Figures 5 and 6 present the progression over time in annual yields of grasses and legumes sown with minimal tillage in cases where these were compared with an unseeded resident pasture. To eliminate the effects of year-to-year variation in potential for growth the yields of the resident pasture have been normalized to their values in the first full production-year of sown pasture.
(= year 1), and the year-by-year yields of minimal-tillage treatments have been adjusted accordingly. When cool-season grasses are sown by minimal tillage into cool- or warm-season grasses, in the majority of cases there is a decline in yield from year 1. When cool-season legumes are sown into cool- or warm-season grasses the change in yield with time is less clear and large increases or decreases in yield are possible. This difference in response of legumes may arise from instances of self-seeding and consequent increase in legume stand (31,37) or from management practices that allow legume to become a dominant component in pasture (89). Management subsequent to pasture establishment is likely to play a major role in sustaining pasture productivity over time (3,11,53). Thom et al. (85) observed that improvements in forage production following overseeding of cool season grass into warm season grass were small and limited to the first six months after sowing because of a lack of persistence of the oversown crop. These authors, however, subjected their pastures to intensive grazing post-renovation, and this may have contributed to the early disappearance of sown species (11,86). Decline in yield of cool-season pastures over time is not unique to establishment by minimal tillage (34,43,69) and data available do not show that grass pastures deteriorate more quickly when sown following minimal tillage than following conventional cultivation.

Effect on seasonal distribution of forage production. The greatest impact of minimal tillage on seasonal distribution of forage production is found when it is used to overseed a crop that has a seasonal growth pattern different from that of the resident pasture. Hence cool-season grasses or cool-season legumes sown into warm-season grasses can extend the period of forage production into late autumn and provide early growth in spring (7,37,40,41,56), or increase yield up to mid-summer (25). Seeding warm-season grass into a
cool-season annual can similarly extend the period of forage production (53). Although overseeding can improve seasonal distribution of yield and provide an increase in total annual yield, gains in production during the winter-spring (October-April) period may be made at the cost of some warm-season forage output (37,40,41). The choice of cool-season crop for overseeding is significant in this regard; oversown early-maturing rye (Secale cereale L.), wheat or oats (Avena sativa L.), appear to present less problem for a companion warm-season grass than do later-growing forage species (56). Minimal-tillage seeding may also influence seasonal distribution of forage output according to its effectiveness in establishing the sown crop, or through damage to resident species resulting from drilling or herbicide application (83). Slower establishment of Italian ryegrass or oats sown into sod of dormant bermudagrass (Cynodon dactylon (L.) Pers.) or bahiagrass (Paspalum notatum Flüggé), in comparison with sowing by conventional tillage, resulted in large reductions in both the proportion and absolute yield of early-season (January-February) forage production (88). Similarly, Mooso et al. (64) observed that greater soil disturbance resulted in more rapid establishment and earlier forage growth, although the initial growth advantage of increased-tillage treatments was not evident in output over a full growing season.

Application of Minimal Tillage Pasture Seeding in Low-Input Systems

In pasture, minimal tillage may be used as an alternative to cultivation and seeding for replacement of existing vegetation, or it may be used with the express intention of retaining some proportion of existing pasture, to reinforce resident vegetation or to introduce species with complementary growth habits. When minimal tillage is used as an alternative to conventional cultivation for pasture establishment, under optimal conditions the cumulative productivity of pastures established by minimal tillage is on average approximately 10% lower than those established by conventional tillage. The long-term effects of minimal tillage on cumulative productivity over successive reseeding cycles have not been reported in the literature. Emergence of seedlings following minimal-tillage broadcasting or drilling is generally less reliable than that following cultivation, but this effect may be minimized by the use of herbicide to suppress resident vegetation in minimal-tilled ground. The limited data available do not show a clear effect of establishment method on persistence, even though sowing into existing pasture is likely to expose introduced plants to a competitive environment very different from that they experience when established following conventional tillage. Allelopathic effects of resident species, soil bulk density effects and insect or other pest damage on non-cultivated ground may all contribute to differences in persistence and long-term productivity of forages established by minimal tillage, compared with those sown conventionally. The possibility of single-pass seeding offered by minimal-tillage techniques, and the savings in cultivation, labor, and tractor time that this implies, may be attractive for low-input farmers who may not have easy access to cultivation and drilling equipment. The need for herbicide suppression for maximum effect of minimum-tillage when used to replace existing pasture may, however, be a disincentive to adoption by low-input farmers because of increased cost and equipment needs. Even though minimal tillage may not increase forage yield, compared with conventional techniques, there are benefits for prevention of soil erosion deriving from its use (70), and these may be of particular relevance for pasture establishment and improvement in low-input production systems and especially those that utilize marginal land. Where minimal tillage is used to complement rather than replace an existing crop, there is usually a gain in annual forage output and an improvement in seasonal distribution of production, even if overseeding reduces the yield of the resident crop. Using minimal tillage to overseed cool-season into warm-season forage provides an average 22% yield benefit, compared with a 13% average yield increase when cool-season is overseeded into cool-season forage (Fig. 7). For low-input systems in particular, increase in annual forage output, together with improvement in seasonal distribution of forage production will facilitate utilization by grazing
and reduce the need for purchase of off-farm feed supplies, or investment in resources for forage conservation.

Pasture establishment presents a risk of total or partial crop failure due to interspecific competition, pest predation, disease, extremes of temperatures, or moisture deficit (16,29). However, the risk of stand failure, and its contribution to long-term aggregate yield, is poorly defined. The frequency of reseed failure is probably underreported in the literature, yet it may have a significant impact on the viability of a reseeding strategy. Stand failure in reseeds may contribute significantly to the extent of production loss in the transition from existing to reseeded pasture, and to the reluctance of low-input producers to engage in pasture improvement. By retaining existing pasture, minimal-tillage seeding may contribute to sustained pasture output in low-input systems by reducing the risk of production loss during reseeding. The effect of minimal tillage procedures on frequency of stand failure, on production loss during establishment of a new seeding and on long-term pasture persistence and productivity, in comparison with conventional tillage and seeding, requires further study.

Early work (1,2,82) showed significant benefit for yield and quality of forage output as a result of reseeding or overseeding grasses or legumes into unimproved pasture, particularly where lime and fertilizer inputs were also provided. However, within systems that have undergone earlier renovation or remediation the benefits of new seeding may not be as great as might be assumed. When compared directly with pasture sown by minimal tillage, unseeded existing pasture averaged 88% of the yield of pastures resown to grass and 75% of the yield of those sown to legumes (Fig. 7). Although improved fertilizer and grazing management is not an invariable alternative to reseeding (35), for many farmers increased fertilizer use (8,13,44,46,78) might be a more beneficial, and less risky, approach to increasing pasture productivity than reseeding or overseeding.
Summary

• Pastures that are established using minimal tillage as an alternative to conventional cultivation and seeding show, under optimal conditions, a reduction in productivity of approximately 10%.

• Suppression of resident vegetation by herbicide application prior to minimal-tillage seeding increases emergence and forage yield of the sown crop.

• Minimal-tillage seeding is likely to be of greatest value in low-input systems when it is used to plant forages that complement rather than replace existing pasture, as this usually provides a gain in annual forage output and an improvement in seasonal distribution of production.

• The limited long-term data available show little difference in persistence of pastures sown with conventional or minimal tillage.

• The incidence of stand failure in resown pastures ranges from 7 to 55% of cases.

• Stand failure or other production loss during establishment of pasture should be considered as potentially important costs in a pasture reseeding program.

• The potential of minimal-tillage seeding for mitigating the effects of stand failure and establishment-phase production loss, and for increasing cumulative forage productivity over repeated cycles of reseeding compared with conventional tillage, requires further study.

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