Factors Causing Losses during the Establishment of Surface-sown Pastures

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Highlight: *Seeds of four pasture species were surface-sown in winter, spring, and summer and losses of seeds, seedlings, and plants during germination, radicle-entry, establishment, and survival noted under various treatments. On an unprotected soil surface losses during germination, radicle-entry and establishment were least in winter and greatest in summer. Dead plant cover on the surface reduced losses during germination and radicle-entry in the summer, while sub-irrigation reduced losses during germination in summer and radicle-entry and establishment in spring and summer. Losses during survival were heavy in all seasons, usually because of moisture stress. Other reasons for losses included harvesting of seeds by ants, damage by soil fauna, residual herbicides, and competition from weeds.*

There are large areas of nonarable hill country on the Tablelands of New South Wales that support low producing native pastures. To increase productivity on these areas it would be necessary to establish improved perennial pastures by aerial methods. However, establishment of perennial pasture species from surface-sowing has been disappointing (Campbell, 1968; Nelson et al., 1970; Dowling et al., 1971). Attention has been drawn to the dearth of information explaining the reasons for such disappointing results (Cullen, 1965; McWilliam et al., 1970; Wilson et al., 1970).

Thus the aim of work reported here was to trace the fate of individual seeds from sowing onwards to determine the reasons for losses and successes. This would allow selection of treatments to assist establishment and indicate problems needing further research. This paper reports the results of three experiments in which the fate of individual seeds was traced after surface-sowing in three seasons. An attempt has been made to interrelate the experiments by having a similar "control" in each.

Materials and Methods

The experiments were conducted on adjacent areas in the field at Armidale N.S.W., Australia. The soil was a yellow podzolic with a structureless surface. The site sloped to the west and was dominated by native perennial grasses. Armidale (altitude 1030 m) has a temperate climate with an average annual rainfall of 78 cm and mean maximum and minimum annual temperatures of 20°C and 7.2°C, respectively.

The species sown were Hunter River lucerne (*Medicago sativa* L.), Woogenellup subterranean clover (*Trifolium subterraneum* L.), Ruanui perennial ryegrass (*Lolium perenne* L.), and Australian phalaris (*Phalaris tuberosa* L.). Seeds were individually dropped onto the soil surface in quadrat areas of 50 x 5 cm and their position marked with a pin. Legume seed was inoculated and lime pelleted. At sowing some seeds were placed on a supernumerary quadrat to provide similarly "weathered" replacements for those taken by ants, while others were placed in petri dishes in a louvred box sited on the ground to provide comparisons between germination under nonlimiting moisture and under field conditions.

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Winter Experiment

Seeds were sown in mid-winter onto a "control" soil surface on which was 1900 kg/ha of dead native pasture. Ten seeds of each species were sown in five random quadrats in each of four blocks. At sowing the percentage ground cover of dead plant tissue and bare ground was 38% and 20%, respectively. The area had been grazed until mid-autumn, when it was treated with a mixture of short-term residual herbicides.

Spring Experiment

Seeds were sown in mid-spring onto a soil surface similar to that in the winter experiment. The quadrats were treated with a mixture of paraquat and diquat five hours before sowing. In each of two blocks, 10 random quadrats were located; five were subirrigated and five were not (controls). Ten seeds of lucerne, subterranean clover, and ryegrass and 14 of phalaris were sown per quadrat. Subirrigation, which began on October 31 and ended in mid-December, was accomplished by filling a shallow trench 2 cm above each quadrat with water three times a day.

Summer Experiment

Seeds were sown in mid-summer onto four treatments: 1) *control*—light cover and no irrigation, 2) *irrigation*—light cover with irrigation, 3) cover—heavy cover and no irrigation, and 4) cover plus irrigation—heavy cover with irrigation. The light and heavy cover treatments had 1130 and 4570 kg dry matter/ha, respectively.

A split plot design with two replications was used, with cover as the main plots and irrigation as the subplots. Each subplot contained five quadrats with ten seeds of each species. All quadrats were treated with paraquat and diquat 4 days before sowing. Subirrigation began on February 8, and ended in May, 1970.

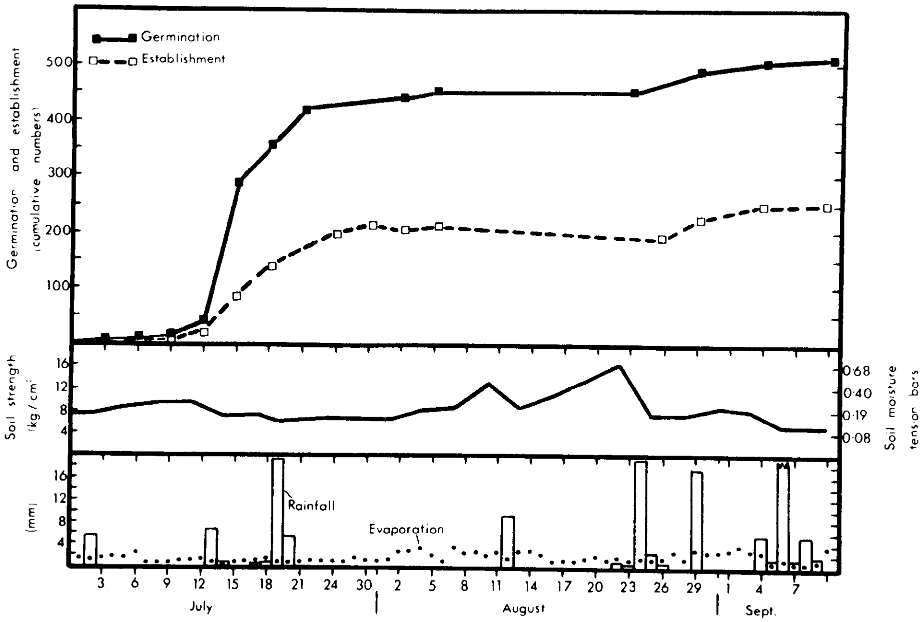

Fig. 1. *Cumulative germination and establishment (total of the four species) in winter, 1969; 800 seeds were sown.*

Table 1. Percentage germination of seeds on the soil surface and in petri dishes in the field, meaned for all species.

Season and treatment	Mean germination
Winter	
Control	64***[1]
Petri dishes	75
Spring	
Control	66***
Irrigation	71 ns
Petri dish	74
Summer	
Control	51***
Irrigation	75 ns
Cover	74 ns
Cover plus irrigation	76 ns
Petri dishes	75

[1] Level of significance for contingency table comparisons between germination on the soil surface and petri dishes within each season: ***$P<0.001$; ns, not significant.

Measurements

In each experiment, observations were made at 3-day intervals for the first 2 or 3 months and thereafter at monthly intervals. Observations were made on germination (protrusion of the radicle through the seed coat); radicle-entry (entry of the radicle into the soil); establishment (development of the seedling for up to 3 months after sowing); and survival (development of the young plant for up to 16 months after sowing). The strength and moisture tension of the soil surface was recorded as well as environment data. A regression relationship between soil strength and soil moisture tension was established (r^2=94) which allowed expression of both parameters by a common line (Figs. 1,2,3).

Results and Discussion

Seeds Taken by Ants

In the 33, 24, and 18 days after sowing in winter, spring, and summer, ants took respectively 29, 42, and 33% of the seeds sown. Harvesting ceased in each season when seeds germinated. The ants took seed of subterranean clover, lucerne, ryegrass, and phalaris in the ratio of 10:46:52:96. It appeared ants preferred the lighter seeds. The species of ant which took most seed was *Pheidole deserticola* Forel.

Campbell (1966) demonstrated that ants can reduce the establishment of surface-sown species especially if dry conditions follow sowing. Seed-harvesting ants are widespread in Australia and other countries; thus, insecticide (Campbell, 1966) or lime-pelleting (Russell et al., 1967) treatments will be necessary to reduce losses. It is unlikely that lime pelleting will be useful in all situations as Campbell (1966) showed ants will take lime pelleted seeds in New South Wales.

Losses During Germination

In each season percentage germination was lower on the control treatments than in the field petri dishes (Table 1). Insufficient moisture was assessed as the main cause of the depressed germination on the controls because germination was higher on treatments that supplied moisture (irrigation), or protected seeds from moisture loss (cover) or did both (cover plus irrigation). In each season germination proceeded in response to a number of intermittent falls of rain (Figs. 1 and 2). Harper and Benton (1966) found that germination of surface-sown seed depended on the moisture relations between seed, soil, and atmosphere. In the results reported here, germination on an unprotected soil surface was higher in winter than in summer due to lower moisture loss from seed and soil in winter. To allow reasonable germination in summer, it appeared that cover was necessary to reduce moisture loss from seed and soil.

Failure of seeds to germinate on the soil surface was also caused by poor

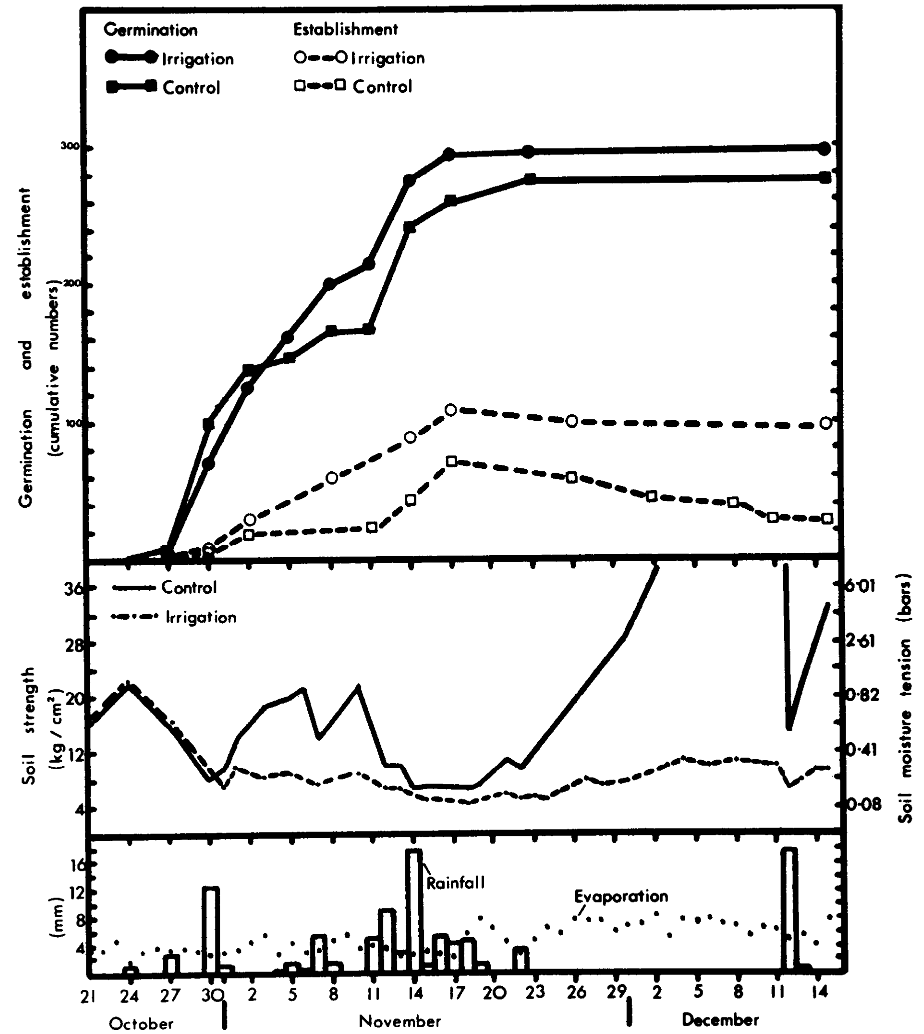

Fig. 2. *Cumulative germination and establishment (total of the four species) on irrigated and control treatments in spring, 1969; 440 seeds were sown on each treatment.*

seed/soil contact, insect damage, radicle "caught" in seed coat, and fungus infection. Losses attributed to these reasons on the control treatments were, 2% in spring, 3% in summer, and 5% in winter.

The effect of temperature on germination appeared minor, because germination in the petri dishes in the field was relatively constant for the three seasons. Moisture tension in the petri dishes would have been similar in each season; thus any difference in germination must have been due to differences in temperature. However, minimum temperatures, lower than those recorded in winter 1969 (mean minimum 0.6°C) can reduce germination (Young et al., 1970) and would have to be considered in environments colder than Armidale.

Seeds which remained ungerminated on the control treatment 3 months after sowing in summer had a mean laboratory germination of 15%, which indicated that "weathering" greatly reduced viability (Wilson et al., 1970).

Losses During Radicle-Entry

Table 2 shows that percentage radicle-entry was higher on the winter control than on the spring or summer control, due most likely to low strength and moisture tension of the soil surface in winter (Fig. 1). Most deaths on these controls occurred because radicles either could not exert sufficient force to deform the soil surface and enter or could not find a suitably sized pore to allow entry and were subsequently desiccated (Table 3). Campbell and Swain (1973) showed that radicle-entry was markedly reduced by small increases in soil strength. In winter, strength of the soil surface during radicle-entry (6.1 to 7.6 kg/cm^2) was close to the minimum measured for this soil, which helps explain the high percentage radicle-entry achieved.

Subirrigation assisted radicle-entry in spring and summer (Table 2) by maintaining a softer and moister soil surface than in the respective control treatments (Figs. 2 and 3). However, losses on the irrigation treatments due to desiccation (Table 3) indicated that a soft, moist soil surface is not sufficient to allow maximum radicle-entry under moderate evaporation.

Under relatively high evaporation in summer, the cover treatment proved more effective than irrigation in assisting radicle-entry (Table 2), despite slightly less favourable soil surface conditions on the former (Fig. 3). This result can be attributed to the protective effect of cover. When cover and irrigation were combined, percentage radicle-entry was higher than on the other three treatments due to favourable surface conditions and protection from desiccation.

Evans and Young (1970) showed that cover increased the relative humidity at the soil surface and decreased the rate at which it dried out. This reduces the danger of desiccation and allows a greater period for radicle-entry. In a controlled environment, McWilliam et al. (1968) showed that radicles of five pasture species could not survive 5 hours of dry conditions. In our study it took 2 days for 50% of the grass radicles and 5 days for 50% of the legume radicles to enter the soil. Cover would also increase surface heterogeneity, reduce temperature extremes (Evans and Young, 1970), frost lift, and the rate at which the soil surface increases in strength in dry periods after rain—all factors which assist radicle-entry (Campbell and Swain, 1973).

Factors other than desiccation (obstructions, disturbance, insect damage, malformed radicles) reduced percentage radicle-entry by from 4% to 11% (Table 3).

The higher percentage radicle-entry of

Table 2. Effect of season of sowing, irrigation, and cover on percentage radicle-entry[1] meaned for all species.[2]

Season and treatment	Mean radicle-entry
Winter	
Control	66
Spring	
Control	38 b
Irrigation	49 a
Summer	
Control	7 d
Irrigation	50 c
Cover	77 b
Cover plus irrigation	90 a

[1] Expressed as a percentage of seeds that germinated.

[2] Means followed by the same letter in the spring or in the summer experiment are not significantly different at the 5% level of probability as determined by Duncan's Range Test.

Table 3. Radicle deaths, meaned for all species, expressed as a percentage of seeds that germinated.

Season and treatment	Cause of death	
	Desiccation	Other reasons
Winter		
Control	24	10
Spring		
Control	54	8
Irrigation	40	11
Summer		
Control	86	7
Irrigation	45	5
Cover	19	4
Cover plus irrigation	6	4

the grasses than of the legumes (Table 4) agrees with findings obtained in a controlled environment (Campbell and Swain, 1973). Because legume radicles have greater difficulty entering the soil, they are slower to enter and thus more subject to losses due to desiccation and soil fauna.

Losses During Establishment

Heavy losses of seedlings during establishment (2.5, 2, and 3 months after sowing in winter, spring, and summer, respectively) on all nonirrigated treatments, except the winter control (Table 5), indicated that moisture stress was the main cause of seedling deaths. The lower death rate in the winter control was due to relatively low evaporation. Death of seedlings attributed to moisture stress on the irrigated treatments was due to desiccation of an exposed part of the radicle, even though the radicle tip had entered the soil.

Losses due to soil fauna (Table 5) were mainly caused by slugs (*Milax gagates* Draparnaud) in the cover treatments in summer and slugs and insect larva in winter; legumes were eaten in preference to grasses. Losses due to residual paraquat and diquat occurred in the cover treatments mainly among grasses. Although losses of seedlings due to soil fauna and residual herbicides were small by comparison with losses due to moisture stress, they can be important in other situations (Suckling, 1951). The effect of residual paraquat in cover can be overcome by allowing an interval of 1 to 2 weeks between spraying and sowing (Warboys and Ledson, 1965). To control slugs, Sucking (1951) recommended grazing prior to sowing; but this would negate the advantages of cover. An alternative is the aerial application of a mulluscicide.

Table 4. Percentage radicle-entry[1] in each season meaned for treatments.[2]

Species	Winter	Spring	Summer
Ryegrass	95 a	63 a	67 a
Phalaris	83 a	77 a	55 b
Lucerne	49 b	15 b	52 b
Subterranean clover	38 b	19 b	51 b

[1] Expressed as a percentage of seeds that germinated.
[2] Means followed by the same letter in each season are not significantly different at the 5% level of probability as determined by Duncan's Range Test.

Losses During Survival

In the winter-sown experiment, losses during the survival period (spring 1969 to spring 1970) comprised 98% of the perennial plants present at establishment. Most (81%) of these deaths occurred in late spring and early summer, 1969, due to competition from volunteer annuals, which grew 15 cm high and reduced light intensity by 80 to 98%. Subterranean clover escaped most of this competition by senescing in summer, 1969.

Grazing has been used in New Zealand before, during, and/or after sowing to control competition and assist pasture species to establish and survive (Suckling, 1959; Cullen, 1970). Although grazing causes loss of some established plants, losses incurred by not grazing could be greater.

Table 5. Deaths of seedlings between radicle-entry and establishment, expressed as a percentage of radicles which gained entry and meaned for all species.

Season and treatment	Cause of death		
	Moisture stress	Soil fauna	Residual herbicide
Winter			
Control	10	11	0
Spring			
Control	57	1	2
Irrigation	18	4	5
Summer			
Control	97	0	0
Irrigation	17	0	2
Cover	62	6	11
Cover plus irrigation	9	9	12

In the spring-sown experiment, 70% of the perennial plants present at establishment died during the survival period (summer, 1969, to spring, 1970) due mainly to periods of moisture stress in autumn and winter, 1970. Although irrigation was continued until establishment there was little difference in percentage survival between irrigated and non-irrigated treatments (Table 6).

In the summer-sown experiment, 52% of plants present at establishment died during the survival period (autumn to

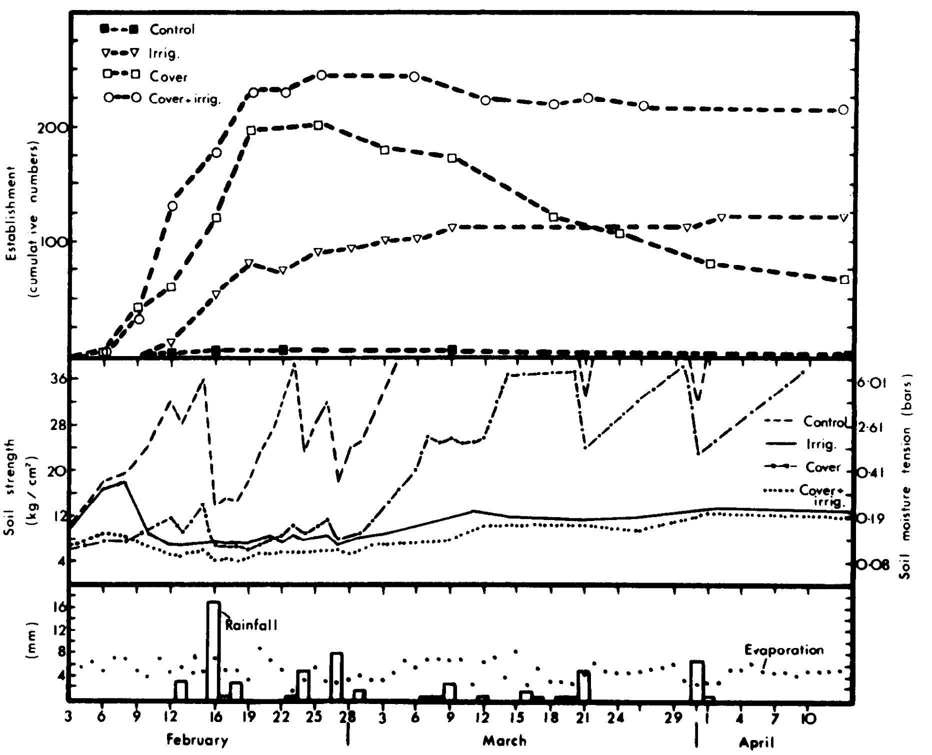

Fig. 3. *Cumulative establishment (total of the four species) on control, irrigation, cover, and cover plus irrigation treatments in summer and autumn, 1970; 400 seeds were sown on each treatment.*

Table 6. Effect of season of sowing, irrigation, and cover on survival, expressed as a percentage of the seeds that germinated on the soil surface.

Season and treatment	Species			
	Ryegrass	Phalaris	Lucerne	Subterranean clover
Winter				
Control	3.3	0	0.6	19.2[1]
Spring				
Control	3.5	5.0	3.3	–
Irrigation	5.4	8.7	6.1	–
Summer				
Control	0	0	1	0
Irrigation	40	18	14	20
Cover	3	3	9	11
Cover plus irrigation	28	51	29	34

[1] Regeneration of subterranean clover.

spring, 1970) mainly because of abnormal moisture stress in winter. The effects of irrigation and cover treatments were still evident at survival (Table 6).

Heavy losses of plants due to moisture stress after radicle-entry could be reduced by larger amounts of cover than were used in the summer experiment, but there appears to be an upper limit determined by the availability of light. Another possibility of overcoming losses in these dry periods could depend on the rapid development of young plants. Plummer (1943) showed that faster, deeper root growth through the soil assisted range seedlings to survive dry periods, while Hoen (1966) found that summer survival of larger phalaris plants was superior to that of smaller plants.

Conclusion

The results of this study provide detailed information on the dynamics of establishment of surface-sown seed. Major losses during establishment were due to ant theft of seed; poor germination; desiccation of the radicle tip; competition from weeds; and moisture stress. Dead plant cover on the soil surface, winter sowing, and other suggested treatments could reduce losses. However, no treatment could be confidently suggested to reduce losses of young plants during periods of severe moisture stress.

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