This is a “preproof” accepted article for Weed Science. This version may be subject to change in the production process, *and does not include access to supplementary material*.
DOI: 10.1017/wet.2024.108

Phenological Patterns and the Impact of Seed Burial Depth and Scarification on the Emergence and Growth of Redweed (*Melochia corchorifolia*)

Dhanu Unnikrishnan[1], Sheeja K Raj[2], Jacob D[3], Shalini Pillai P[4], Ameena M[5] and Bhagirath Singh Chauhan[6]

[1]PhD Scholar, Department of Agronomy, Kerala Agricultural University, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India; [2]Assistant Professor (0000-0002-3068-7494), Department of Agronomy, Kerala Agricultural University, College of Agriculture Vellayani, Thiruvananthapuram, Kerala, India; [3]Assistant Professor and Head, Kerala Agricultural University, OFR Centre, Onattukara Regional Agricultural Research Station, Kayamkulam, Kerala, India; [4]Professor and Head, Kerala Agricultural University, Department of Agronomy, Kerala Agricultural University, College of Agriculture Vellayani, Thiruvananthapuram, Kerala, India;[5]Professor, Kerala Agricultural University, Department of Agronomy, College of Agriculture Vellayani, Thiruvananthapuram, Kerala, India; and [6]Professor, Centre for Crop Science, Queensland Alliance for Agriculture and Food Innovation, University of Queensland, Gatton, Australia

Author for correspondence: Sheeja K Raj, Assistant Professor, Department of Agronomy, Kerala Agricultural University, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India, 695 522, Email: sheeja.raj@kau.in

Short title: Redweed emergence

Abstract

Redweed a tropical erect branched herb, is one of the predominant broadleaf weeds affecting upland crops in the Onattukara Sandy Plains, Kerala, India. Experiments were conducted in a screenhouse at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India, to determine the effects of seed burial depth and seed scarification on emergence indices and growth attributes of redweed. Scarification stimulated emergence and resulted in greater values for emergence indices and seedling parameters. The seedling emergence of redweed was influenced by seed burial depth. Shallow seed burial (2 cm) of scarified and non-scarified seeds resulted in greater seedling length (70 cm and 58 cm, respectively), seedling biomass (0.72 g and 0.48 g, respectively), emergence percentage (60% and 32%, respectively), and greater values for other emergence indices. As the depth of seed burial increased from 2 cm, emergence and seedling biomass decreased, exhibiting lower values for the emergence indices. Correlation and regression studies revealed that seed burial depth of scarified and non-scarified seeds greater than 2 cm had a negative effect on seedling emergence and biomass of redweed. Weed biology studies indicated that redweed displayed notable consistency in its phenological traits, regardless of the location where the seeds were collected, as little ecotype variability was observed. Emergence occurred in 6 d, 50% flowering in 44 d, capsule formation in 56 d and maturity in 76 d. On average, a single plant produced 277 seeds and had a 100 seed weight of 0.31 g. A stale seedbed with shallow tillage or deep plowing to a depth of 10 cm before sowing can be adopted to reduce the infestation of redweed.

Nomenclature: Redweed, *Melochia corchorifolia* L.

Keywords: Emergence indices; seedling biomass; seedling length.

Introduction

Redweed, a tropical erect branched shrub belonging to the Malvaceae family, consistently yields flowers and fruits throughout the year, showcasing widespread distribution across tropical and subtropical regions in Africa, Asia, and Australia. Its short life cycle, prolific seed production, and adaptability to a diverse array of soils have facilitated the extensive infestation of redweed in upland areas. Although it is suited for xerophytic conditions, redweed also exhibits the capability to flourish in both mesophytic and hydrophytic environments. It is a predominant weed in rice (*Oryza sativa* L.) and other upland crops, contributing to elevated production costs and substantial yield reductions. Reported yield losses in upland rice due to redweed infestation can reach 67% (De Datta and Llagas 1984).

Redweed is also a predominant broadleaf weed in carrot [*Daucus carota* ssp. s*ativus* (Hoffm.)], potato (*Solanum tuberosum* L.) (Yakubu et al. 2006) and maize (*Zea mays* L.) - cowpea (*Vigna unguiculata* L. Walp.) intercropping systems in Nigeria (Takim and Fadayomi 2010). It was also identified as a major weed of upland rice in Philippines (Pullaiah 2014), aerobic rice in Malaysia (Sunyob et al. 2015), direct dry seeded rice (DSR) in Nepal (Chaudhary et al. 2018), and wet and DSR in Northwest Cambodia (Martin et al. 2021). Redweed infestation has been reported in the cotton (*Gossypium hirsutum* L.) growing areas of Turkey (Jabran 2016) and soybean (*Glycine max* L.) fields in Indonesia and Thailand (Pullaiah 2014).

Among the various factors affecting weed establishment, seed burial depth and seed scarification are two key variables that can significantly impact the emergence and subsequent growth of weed species. Seed burial depth refers to the vertical placement of seeds within the soil profile, while seed scarification involves mechanical or chemical treatments that alter the seed coat to enhance water and oxygen penetration. The depth at which weed seeds are buried in the soil can influence their exposure to factors such as temperature, moisture, and light availability. Seeds buried at different depths may encounter variations in these conditions, leading to differences in seedling emergence and emergence rate. Conversely, seed scarification can break seed dormancy and promote germination by facilitating water absorption and gas exchange. Weed seeds often possess hard seed coats that can act as barriers to water penetration. Scarification methods, such as physical abrasion or chemical treatments, aim to overcome these barriers, enhancing the likelihood of successful emergence.

In the field, seeds of redweed are observed to be distributed both on the surface and within soil layers. Disturbance of the soil through tillage and stale seedbed practices can influence the germination and emergence of these seeds. Dormancy in redweed is due to a hard seed coat (Eastin 1983). Tillage can invigorate germination by seed coat scarification (Chauhan et al. 2006). Chauhan and Johnson (2008) conducted separate experiments to assess the effect of seed burial depth (0 to 10 cm) and seed scarification with concentrated sulfuric acid at different durations (0, 5, 10, 30, 60, 120 and 180 min) on the seedling emergence of redweed in the Philippines over a study period of 10 d. The present study conducted for a period of 31 d, aimed to assess the effect of seed burial depth on seedling emergence and seedling vigor of scarified (mechanical) and non-scarified seeds of redweed. Also, the prevalent ecotype in Onattukara could potentially be different from that in the Phillipines. Therefore, a detailed study was essential in this region to better understand the specific emergence patterns and seedling establishment requirements in order to develop effective management strategies for redweed.

Phenological investigations provide insights into the functional patterns of weeds and weed communities, enhancing the precision of estimating when and how weed competition impacts crop yield in specific agronomic systems, and enabling the development of more targeted control measures.

This research aims to explore the interactive effects of seed burial depth and seed scarification on the emergence and seedling growth of redweed. Furthermore, the research is directed towards understanding the developmental phases of redweed, with a focus on systematically analyzing the various growth stages associated with its life cycle. Understanding the optimal burial depth for redweed can provide valuable insights into its ecological preferences and aid in the development of targeted weed management practices. Investigating the impact of seed scarification on redweed emergence can contribute to the development of strategies that exploit seed dormancy mechanisms for more effective weed control.

Materials and Methods

Impact of Seed Burial Depth and Scarification on Emergence and Seedling Growth Parameters of Redweed

Trials were conducted in a screenhouse at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India, from March to May 2021. The first trial was conducted from March 10, 2021 to April 9, 2021 and the confirmatory trial from April 20, 2021 to May 21, 2021.

Experiments were laid out in a completely randomized design (CRD) with two factors replicated three times. Three pots were maintained for each treatment per replication. The first factor was seed burial depth (0, 2, 4, 6, 8, and 10 cm) and the second factor was seed scarification (mechanical scarification and no scarification).

Seed capsules of redweed were hand-harvested from a sesame (*Sesamum indicum* L.) field at the Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, Kerala, India, in February 2021. The field (8.93° to 9.35°N and 76.39° to 76.69°E at 3.05 m MSL), located in the Onattukara Sandy Plains, had been under rice-rice-sesame rotation for several years and consisted of loamy sand with 86% sand, 6% silt, and 8% clay. Seeds were separated from capsules by hand, allowed to dry for 2 weeks at 25 °C, sieved to remove extraneous matter, and then stored in airtight plastic containers until experimentation. The thousand-seed weight of redweed was 3.0 ± 0.20 g. Mechanical seed scarification was performed by spreading seeds on a wooden board and rubbing with emery cloth of grit size 220 (fine grade) moving 10 cm up and down three times based on the technique of Mobli et al. (2020).

Average maximum and minimum temperatures inside the screenhouse were maintained at 34.0 and 23.3 °C, respectively during the study period. The soil used for the trials was collected from ORARS fields. The soil was sterilized by autoclaving at 121 °C and 1.5 atm for 2 h. Cylindrical pots, 22 cm tall and 20 cm diameter, were used for the study. For the sowing depth experiments, 25 seeds were placed at 0 (soil surface), 2, 4, 6, 8, and 10 cm below the soil surface. This was achieved by filling the pot with soil to the corresponding level below the surface, placing the seeds, and filling the remainder of the pot with soil. The pots were irrigated as needed to maintain adequate moisture for seedling emergence and growth.

Seedlings were considered emerged when the cotyledons protruded above the soil surface. Seedling emergence was counted daily and remained unchanged after 15 d. At 31 d after seeding (DAS), seedlings were removed and root and shoot lengths were measured. Shoots and roots were separated and dried at 65 ± 5 C to a constant moisture content. Shoot and root biomass were recorded and expressed as g plant^{-1}. Emergence percentage (EP), emergence index (EI) (Bench et al. 1991), emergence rate index (ERI) (Esechie 1994), speed of emergence (SE) (Bartlett 1973), seedling vigor index I (SVI I), and seedling vigor index II (SVI II) (Abdul-baki and Anderson 1973) were determined using the following formulae.

1) Emergence percentage (EP) =

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

(Total number of seedlings emerged/Total number of seeds) * 100

2) Emergence index (EI) = (30 * n_1) + (29 * n_2) + ……… + (1 * n_{30})

   Where n_1, n_2…..n_{30} = are the numbers of seedlings emerged on the first, second, and subsequent days until the 30th day; 30, 29…. and 1 are weightage assigned to the number of seedlings emerged on the 1st, 2nd and 30th day, respectively.

3) Emergence rate index (ERI) = (G_1* 100)/1 + (G_2 *100)/2 + ………..+ (G_n100)/n

   Where G_1 and G_2 are the emergence percentage on the 1st and 2nd day after sowing, and G_n is the emergence percentage on the nth day after sowing.

4) Speed of emergence (SE) = n_1/d_1 + n_2/d_2+………..+ n_x/d_x.

   Where n_1 is the number of seedlings emerged on the 1st day, n_2 is the number of seedlings emerged on the 2nd day……….and n_x is the number of seedlings emerged on the xth day, d_1 is the 1st day, d_2 the 2nd day and d_x the xth day.

5) Seedling vigor index I (SVI I) = Seedling length (cm) * Emergence percentage

6) Seedling vigor index II (SVI II) = Seedling biomass (g) * Emergence percentage

Studies on Weed Biology and Germination Behaviour of Redweed

Two trials, the first trial from May 01 to July 20, 2021 and the second trial from May 10 to July 30, 2021) were conducted in a screenhouse at the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India to study the biology and germination behavior of redweed. The average maximum and minimum temperatures inside the screenhouse were maintained at 34.0 and 23.3 °C, respectively. Seeds of redweed were collected from 10 distinct locales within the sesame-growing regions of Karthikapally, Karunagapally and Mavelikkara in the Onattukara Sandy Plains in the Kollam and Alappuzha districts of Kerala, India (Figure 1). Seeds were cleaned and stored as mentioned in the previous study. The pot size was the same as in the previous study and was filled with a potting mixture comprising sterilized river sand and vermicompost (1.5% N, 0.4% P_2O_5 and 1.8% K_2O) in 1:1 ratio. Fifteen scarified seeds of redweed were sown at a depth of 2 cm in each pot. At 7 DAS, pots were thinned to five plants. Pots were irrigated with an equal quantity of water (1.25 L per pot) twice a week throughout the study. The three regions from which seeds were collected served as treatments and the 10 distinct locales in each region were considered replications.

Statistical Analyses

For both experiments, data from the two trials were pooled and subjected to statistical analysis, as no significant interactions were observed between treatments and the trials. Experimental data were analyzed using the analysis of variance (ANOVA) technique as suggested by Panse and Sukhatme (1985) with a factorial CRD for the first experiment and CRD for the second experiment. Significance was tested using the F- test (Snedecor and Cochran, 1967) and the least significance difference (LSD) was calculated at $P < 0.05$ to denote significant differences. Pearson correlation analysis and regression analysis were conducted to determine the relationships among, seed burial depth, emergence indices, and growth parameters. All statistical analyses were carried out using Grapes Agri 1, an open-source R package for agricultural research data analysis, developed by scientists at Kerala Agricultural University and the Indian Agricultural Statistics Research Institute, New Delhi (Gopinath et al. 2021).

Results and Discussion

Effect of Seed Burial Depth and Scarification on Seedling Emergence

Seedling emergence of redweed was first observed at 3 DAS and seed burial depth greatly influenced seedling emergence (Table 1). Surface-placed seeds (0 cm) of both scarified and non-scarified seeds had reduced emergence compared to seeds buried at depths from 2 cm, 4 cm and 6 cm, but greater emergence than those buried at 8 cm and 10 cm. This reduced emergence might be due to the drying of the upper soil layer, leading to the desiccation of germinated seeds. Ghorbani et al. (1999) suggested that the diminished emergence of surface-sown seeds could be attributed to restricted soil-seed contact, resulting in inadequate water imbibition by the seeds. Chauhan (2016) also observed lower seedling emergence of bladder ketmia (*Hibiscus tridactylites* Lindl.) from surface-placed seeds compared to those placed at 1 cm and 2 cm depths, likely due to reduced seed-to-soil contact and subsequent poor water imbibition.

Seed burial depth and scarification impacted emergence (Table 1). Scarified and non-scarified seeds buried at a depth of 2 cm exhibited the greatest emergence (60% and 32%). Seedling emergence decreased with increasing depth. Seeds buried at 10 cm resulted in lower emergence both in scarified (7%) and non-scarified (4%) seeds, which was 88% less than seeds buried at 2 cm. This might be due to the increased energy demand for emergence at greater depths, which could have resulted in reduced shoot growth. Benvenuti et al. (2001) reported a decrease in seedling emergence as seed burial depth increased. In little mallow (*Malva parvifolia* L), shallow

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

seed burial (0.5 to 2 cm) resulted in 60 to 62% seedling emergence, with further increases in depth leading to reduced emergence (Chauhan et al. 2006). A previous study on redweed (*Melochia concatenata* synonym: *Melochia corchorifolia*) indicated that seedling emergence was the highest for seeds buried at depths of 0-2 cm, progressively decreasing with increasing depth, with no emergence at 8 cm (Chauhan and Johnson, 2008).

The present study also found a decrease in emergence with increasing burial depth. However, in contrast to the findings of Chauhan and Johnson (2008), we observed that surface-placed scarified and non-scarified redweed seeds exhibited lower emergence percentage (17% and 8%, respectively). Both scarified and non-scarified seeds, however, showed a higher emergence percentage at a 2 cm depth – a fourfold increase compared to the surface placed seeds. Further, emergence of scarified and non-scarified redweed seeds was observed at 8 cm and 10 cm depths in the present study, contrasting with the previous findings by Chauhan and Johnson (2008) of no emergence at 8 cm.

Physical dormancy is common among Malvaceae species (Harris 1981). The emergence of non-scarified seeds tends to decrease by 46% compared to scarified seeds in redweed. Mechanical scarification caused abrasion or scratches on the seed coat, that enabled the seeds to overcome dormancy by allowing water imbibition. Physically scarified seeds of little mallow exhibited significantly greater emergence (88%) compared to non-scarified seeds (10%) (Chauhan et al. 2006). The greater emergence observed in scarified seeds of redweed compared to non-scarified seed might be attributed to improved water imbibition through a weakened seed coat. Enhanced germination due to scarification was reported in Caeserweed (*Urena lobata* L.), another weed in the family Malvaceae (Awan et al. 2014). Seeds of Venice mallow (*Hibiscus trionum* L.) exhibited greater seedling emergence when buried at a 2 cm depth (54%) compared to surface-placed seeds (38%) (Chachalis et al. 2008).

Effect of Seed Burial Depth and Scarification on Emergence and Seedling Vigor Indices

The depth of seed burial and seed scarification impacted emergence and seedling vigor indices of redweed. While comparing scarified and non-scarified seeds, scarified seeds showed greater emergence and seedling vigour indices at all seed burial depths (Table 1). Scarified seeds buried at 2 cm had the greatest values for EI, ERI, SE, SVI I and SVI II (Table 1). Conversely, non-scarified redweed seeds placed at 10 cm exhibited lower emergence indices including, EI, ERI, SE

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

and seedling vigor indices SVI I and SVI II which were comparable to non-scarified seeds buried at 8 cm (Table 1).

The speed of emergence indicates the total number of seeds that germinate and emerge within a given time interval; greater values indicate, greater and faster emergence. Compared to 2 cm, a 93% reduction in the speed of emergence was observed in seeds placed at 10 cm. The EI and ERI also declined by 90 and 92%, respectively, compared to seeds buried at 2 cm. Greater emergence indices in scarified and non-scarified seeds are related to the availability of seed storage reserves for seedling growth. Lower values for emergence indices as noted in seeds buried below 6 cm (Table 1), could be attributed to the depletion of available seed food reserves as the seedlings grow towards the soil surface. According to Benvenuti et al. (2001), the average emergence time for velvetleaf (*Abutilon theophrasti* Medicus) was less for seeds positioned at 2 cm (6.8 d) compared to those buried at 10 cm (19.7 d). The emergence index and mean emergence time decreased with increasing seeding depth beyond 2 cm in field bindweed (*Convolvulus arvensis* L.) (Tanveer et al. 2013). An increase in burial depth beyond the tolerable limit would inhibit the normal growth and development of plants (Sun et al. 2010). Greater seedling vigor index values observed at 2 cm seeding depth in scarified and non-non scarified seeds were due to greater seedling length and biomass (Table 2). In whitebark senna [*Senna spectabilis* (DC*)* H.S. Irwin Barnby], seeds buried at 2 cm resulted in greater SVI (Sikuku et al. 2018). Seeds positioned on the surface (0 cm) had lesser values for emergence indices compared to those buried at 2 cm in both scarified and non-scarified seeds (Table 1). Surface soil does not provide adequate humidity required for seed germination and growth (Guo et al. 2010); also, seeds located on the soil surface had little chance to germinate due to low soil moisture caused by evaporation (Liu et al. 2011).

Scarification had a significant impact on the emergence indices of redweed. Non-scarified seeds exhibited a decrease of 44%, 50%, 42%, 55%, and 62% for EI, ERI, SE, SVI I, and SVI II respectively, compared to scarified seeds. Redweed exhibits notably low emergence indices in the absence of scarification treatment. Malvaceae species commonly exhibited physical dormancy, as noted by Harris (1981). Scarification can break down exogenous dormancy by permeabilizing the seed coat, facilitating water imbibition and embryo expansion (Matilla, 2008; Huang et al. 2017).

Effect of Seed Burial Depth and Scarification on Seedling Parameters

Seed burial depth and seed scarification affected the emergence and development of redweed seedlings. Variation in seedling length was observed in response to changes in burial depth in both

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

scarified and non-scarified seeds; however, greater values were observed in scarified seeds (Table 2). Scarified seeds buried at 2 cm produced longer shoots and roots compared to deeper depths (6, 8 and 10 cm) but were on par with scarified seeds placed at 4 cm. Seedling length was greater in scarified seeds placed at 2 cm than in deeper depths (Table 2). Seedlings that emerged from non-scarified seeds placed at 10 cm depth exhibited markedly small shoots, roots, and overall seedling lengths (Table 2).

Surface-placed (scarified and non-scarified) seeds (0 cm) had less seedling length compared to seeds placed at 2 cm and 4 cm (Table 2). Surface-placed seeds (0 cm) are subjected to regular soil drying due to moisture loss through evaporation. Sowing to a depth of 2 cm proves advantageous by offering seeds prolonged access to moisture. Consequently, this extended moisture availability enables seedlings to develop deeper root systems, facilitating access to water sources at greater depths. These results align with Awan et al. (2014) who observed that surface placed Caesarweed (*Urena lobata* L.) recorded lesser seedling biomass than those placed at 1 cm. A decrease in seedling length of redweed by 74% was noted in seeds positioned at a depth of 10 cm compared to those at 2 cm. Seeds with larger food reserves can generate long hypocotyls, aiding their emergence above the surface. The decline in shoot length with increasing seed burial depth suggests that seeds may have utilized their storage reserves for growth while moving towards the soil surface. Deeply buried seeds did not have adequate energy reserves for the seedlings to grow to the surface (Jorgensen et al. 2019).

The depth at which seeds were buried and seed scarification affected shoot, root and seedling biomass of redweed seedlings (Table 2). Seedlings emerging from scarified seeds buried at a depth of 2 cm exhibited greater shoot, root, and overall seedling biomass. Seedling biomass, though lower did not vary significantly between scarified and non-scarified seeds placed at 10 cm.

A reduction in seedling biomass of redweed 93% was observed in seeds placed at 10 cm, compared to seeds placed at 2 cm depth. The reduction in seedling biomass in seeds buried at deeper depths might be due to a lack of sufficient oxygen, light, moisture, and temperature; the factors essential for plant growth (Soltani et al. 2013). The reduction in the number of leaves and leaf area, as a result of depleted seed food reserves, and the lack of oxygen and light at greater depths (8 and 10 cm), could potentially have influenced photosynthesis and dry matter production. Seeds buried at deeper depths experienced anoxic conditions and had negative redox values leading to exposure to reduced metabolites and increased seed mortality (Jorgensen et al. 2019).

Observations on wild oat (*Avena fatua* L.) indicated a consistent decrease in both shoot and root biomass as burial depth increased. Seeds of wild oat buried at 10 cm exhibited a decline in shoot and root biomass of 60% and 55%, respectively, compared to seeds sown at a depth of 4 cm. The decrease in root biomass with increasing seed burial depth was attributed to reduced light diffusion, elevated mechanical resistance posed by the soil, and decreased seed viability (Maqbool et al. 2020).

Scarification positively impacted both seedling length and biomass. In contrast, non-scarified seeds of redweed exhibited a decline in seedling length and biomass by 19% and 30%, respectively, as compared to scarified seeds. Increase in shoot and root length and shoot and root biomass) resulted in greater seedling length and biomass (Table 2) in scarified seeds. Scarification allows the seeds to imbibe water quickly (Chauhan et al. 2006), which enhances seedling emergence and enables faster growth.

Pearson correlation analysis revealed a negative correlation between seed burial depth and emergence parameters (Figure 2). Regression analysis investigating the influence of depth on seedling length and biomass of both scarified and non-scarified seeds of redweed revealed highly significant negative regression values (Figures 3, 4, 5 and 6). Regression analysis supported the findings of the study, showing that seedling length and biomass of both sacrificed and non-sacrificed seeds were adversely affected at depths greater than 2 cm, but an increase in seedling length and biomass has been observed from 0 to 2 cm. The regression model for seedling length and seedling biomass of scarified and non-scarified seeds followed a second order polynomial.

Studies on Weed Biology and Germination Behavior of Redweed

Redweed displayed notable consistency in its phenological traits regardless of the locations from where the seeds were collected. Analysis of growth and yield characteristics unveiled intriguing patterns. Maximum emergence of redweed was observed on the 6th day, with first flowering appearing on the 42nd d, and plants attained a height of 75.6 cm at harvest. On average, a single plant produced 277 seeds, with a 100-seed weight of 0.31 g. Analysis of the growth stages of redweed revealed that, on average, the vegetative phase spanned 35 d, with 50% flowering occurring at 44 d, capsule formation at 56 d, and maturity at 76 d.

Engel et al. (2011) reported that changes in environment and soil conditions may cause morphological variability in a species. Precipitation is a major factor determining the functional traits in *Stipa* species (Lu et al. 2016) and Wang et al. (2020) reported that precipitation varies

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

considerably with changes in longitude. The three regions (Karunagapally, Karthikapally, and Mavelikkara) are located at the same longitude of 76°E, which may explain the lack of variations observed in the growth stages of redweed among these locations.

In summary, experiments demonstrated that shallow burial depth (2 cm) promoted the seedling emergence and early morphological development of redweed compared to deeper seed burial depths. Deeper burial negatively affected both seedling emergence and seedling biomass. Scarification consistently improved emergence and biomass across all burial depths, highlighting its role in stimulating seedling emergence. The greater emergence observed from 2 cm suggests that the stale seedbed technique should be emphasized to minimize early crop-weed competition and mitigate yield loss associated with redweed infestation. Additionally, deep tillage operations (burying seeds beyond 10 cm) before the sowing of sesame could help suppress the buildup of the redweed seed bank in the long term.

Practical Implications

Understanding the biology and effects of seed burial depth on redweed helps in designing management practices to reduce weed emergence and develop eco-friendly weed management approaches. Shallow seed burial (2 cm) promotes greater seedling emergence compared to deep seed burials. This suggests that deep tillage practices to bury seeds (beyond 10 cm) can disrupt seedbank buildup. Deep seed burials negatively affect both emergence and seedling biomass and can potentially suppress weed seedbank establishment. The greater emergence of redweed from 2 cm suggests that the stale seedbed technique, which allows for weed emergence that is subsequently killed with shallow tillage before the sowing of crops, could be a useful strategy to minimize early competition and mitigate yield losses. Mechanical scarification weakens the seed coat and improves the emergence and biomass accumulation of redweed. This suggests that any type of tillage immediately after sowing the crop should be avoided to reduce redweed emergence and avoid crop-weed competition in the early stages of the crop. Integrating knowledge of weed biology, seed burial depth, and scarification can help in developing effective weed management interventions, ultimately helping farmers optimize crop yield while minimizing redweed-related losses.

Acknowledgments

The Authors acknowledge Kerala Agricultural University, Thrissur, Kerala, India for providing infrastructure facilities for the conduct of experiments.

Funding

Competing Interests

The authors declare no competing interests.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

References

Abdul-Baki AA, Anderson JD (1973) Vigor determination in soybean seed by multiple criteria. Crop Sci 13: 630-633

Awan TH, Chauhan BS, Cruz PCS (2014) Influence of environmental factors on the germination of *Urena lobata* L. and its response to herbicides. PLoS ONE 9(3): e90305. doi:10.1371/journal.pone.0090305. Accessed: November 1, 2022

Bartlett MS (1973) Some examples of statistical methods of research in agriculture and applied biology. J R Stat Soc 4: 137-183

Bench ARL, Fenner M, Edwards PJ (1991) Changes in germinability, ABA content and ABA embryonic sensitivity in developing seeds of *Sorghum bicolor* (L.) Moench. induced by water stress during grain filling. New Phytol 118: 339-347

Benvenuti S, Macchia M, Miele S (2001) Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. Weed Sci 49: 528-535

Chachalis, D., Korres, N., and Khah, EM (2008) Factors affecting seed germination and emergence of Venice mallow (*Hibiscus trionum*). Weed Sci 56 (4): 509-515

Chaudhary SK, Marahatta S, Chaudhary M (2018) Performance of dry direct seeded rice and weeds on Sesbania brown manuring as compared to farmers practice and chemical control method. Int J Appl Sci Biotechnol 6: 265-269

Chauhan BS, (2016) Germination biology of *Hibiscus tridactylites* in Australia and the implications for weed management. Sci Rep 6(1), p.26006. doi: 10.1038/srep26006. Accessed: October 26, 2022

Chauhan BS, Gill GS, Preston C (2006) Tillage system effects on weed ecology, herbicide activity and persistence: a review. Aust J Exp Agric 46:1557-1570

Chauhan BS, Johnson DE (2008) Seed germination and seedling emergence of nalta jute (*Corchorus olitorius*) and redweed (*Melochia concatenata*): Important broadleaf weeds of the tropics. Weed Sci 56 (6): 814-819

De Datta, SK, Llagas MA (1984) Weed problems and weed control in upland rice in tropical Asia. In: *An Overview of Upland Rice Research*, Bouake, Ivory Coast, IRRI, Los Banos, Philippines, Pp. 321-341

Eastin EF (1983) Redweed (*Melochia corchorifolia* L.) germination as influenced by scarification, temperature, and seeding depth. Weed Sci 31: 229-231

Engel, K, Tollrian, R, Jeschke, JM (2011) Integrating biological invasions, climate change and phenotypic plasticity. Comm Integ Biol 4(3): 247–250

Esechie HA (1994) Interaction of salinity and temperature on the germination of sorghum. J Agron Crop Sci 172: 194-199

Ghorbani, R, Seel W, Leifert, C (1999) Effects of environmental factors on germination and emergence of *Amaranthus retroflexus*. Weed Sci 47(5): 505-510

Gopinath PP, Prasad R, Joseph B, Adarsh VS (2021) GrapesAgri1: Collection of Shiny Apps for Data Analysis in Agriculture. J Open Source Softw 6: 34-37

Guo CR, Wang ZL, Lu JQ (2010) Seed germination and seedling development of *Prunus armeniaca* under different burial depths in soil. J For Res 21(4): 492-496

Harris PJC (1981) Seed viability, dormancy, and field emergence of *Urena lobata* L. in Sierra Leone. Trop Agric 58(3): 205-213

Huang W, Mayton HS, Amirkhani M, Wang D, Taylor AG (2017) Seed dormancy, germination and fungal infestation of eastern gamagrass seed. Ind Crops Prod 99 (1): 109-116

Jabran K (2016) Weed flora, yield losses and weed control in cotton crop. Julius-Kühn-Archiv 452: 177

Jorgensen MS, Labouriau R, Olesen B (2019) Seed size and burial depth influence *Zostera marina* L. (eelgrass) seed survival, seedling emergence and initial seedling biomass development. PLoS ONE 14(4): e0215157. https:// doi.org/10.1371/journal.pone.0215157. Accessed: October 22, 2022

Liu HL, Shi X, Wang JC, Yin LK, Huang ZY, Zhang DY (2011) Effects of sand burial, soil water content and distribution pattern of seeds in sand on seed germination and seedling survival of *Eremosparton songoricum* (Fabaceae), a rare species inhabiting the moving sand dunes of the Gurbantunggut Desert of China. Plant Soil 345: 69-87

Lu X, Zhou G, Wang Y, Song X (2016) Effects of changing precipitation and warming on functional traits of zonal Stipa plants from Inner Mongolian grassland. J Meteorol Res 30(3): 412-425

Maqbool MM, Naz S, Ahmad T, Nisar MS, Mehmood H, Alwahibi MS, Alkahtani J (2020) The impact of seed burial depths and post-emergence herbicides on seedling emergence and biomass production of wild oat (*Avena fatua* L.): Implications for management. PLoS One. 2020 Oct 28;15(10): e0240944. doi: 10.1371/journal.pone.0240944. Accessed: October 22, 2022

Martin R, Chhun S, Yous S, Rien R, Korn C, Srean, P (2021) Survey of Weed Management Practices in Direct-Seeded Rice in North-West Cambodia. Agron 11: 498

Matilla AJ (2008) Desarrollo y germinación de las semillas. Fundamentos de fisiologia Vegetal 2: 549

Mobli A, Mollaee M, Manalil S, Chauhan BS (2020) Germination ecology of *Brachiaria eruciformis* in Australia and its implications for weed management. Agron 10: 30

Panse VG, Sukhatme PV (1985) Statistical Methods for Agricultural Workers 4th ed. New Delhi: Indian Council of Agricultural Research. 369 p

Pullaiah, T (2014) Ethnobotany, phytochemistry and pharmacology of *Melochia corchorifolia* L. Int Res J Pharm 5: 128-131

Sikuku PA, Musyimi DM, Amusolo M (2018) Effect of seed depth on germination, growth and chlorophyll contents of *Senna spectabilis*. Discov Sci 14: 84-92

Snedecor GW, Cochran W G (1967) Statistical Methods. 6th ed. Ames: Lowa State University Press. 593p

Soltani E, Soltani A, Galeshi S, Ghaderi-Far, F, Zeinali E (2013) Seed bank modelling of volunteer oil seed rape: from seeds fate in the soil to seedling emergence. Planta Daninha 31(2): 267-279

Sun Z, Mou X, Lin G, Wang L, Song H, Jiang H (2010) Effects of sediment burial disturbance on seedling survival and growth of *Suaeda salsa* in the tidal wetland of the Yellow River estuary Plant and Soil 337(1): 457-468

Sunyob NB, Juraimi AS, Hakim MA, Man A, Selamat A Alam MA (2015) Competitive ability of some selected rice varieties against weed under aerobic condition. Int J Agric Biol 17: 61-70

Takim FO, Fadayomi O (2010) Influence of Tillage and Cropping Systems on Field Emergence, Growth of Weeds and Yield of Maize (*Zea mays* L.) and Cowpea (*Vigna unguiculata* L.). Aus J Agric Eng 1(4): 141-148

Tanveer A, Tasneem M, Khaliq A, Javaid MM, Chaudhry MN (2013) Influence of seed size and ecological factors on the germination and emergence of field bindweed (*Convolvulus arvensis*). Planta Daninha 31: 39-51

Wang M, Zhang J, Guo Z, Guan Y, Qu G, Liu J, Guo Y, Yan X (2020) Morphological variation in *Cynodon dactylon* (L.) Pers., and its relationship with the environment along a longitudinal gradient. Hereditas 157: 1-11

Yakubu AI, Alhassan J, Lado A, Sarkindiya S (2006) Comparative weed density studies in irrigated carrot (*Daucus carota* L.), potato (*Solanum tuberosum* L.) and wheat (*Triticum aestivum* L.) in Sokoto-Rima Valley, Sokoto State, Nigeria. J Plant Sci 1(1):14-21

Table 1. Emergence and vigor indices of redweed as influenced by seed scarification and seed burial depth.[a,b]

Seed scarification[c]	Seed burial depth[d]	Emergence indices[e]								Seedling vigor indices[f]			
		EP[g]		SE[g]		EI[g]		ERI[g]		SVI I[g]		SVI II[g]	
	cm	%											
Mechanical scarification	0	17	e	0.57	e	94	e	23	e	977	e	9.2	e
	2	60	a	2.25	a	335	a	89	a	4108	a	43.4	a
	4	43	b	1.54	b	248	b	63	b	2848	b	26.3	b
	6	27	d	0.83	d	144	d	35	d	1373	d	12.6	d
	8	9	fg	0.21	fg	45	gh	10	gh	327	fg	2.4	fg
	10	7	gh	0.14	g	31	hi	6	hi	135	h	0.3	h
No scarification	0	8	g	0.34	f	49	g	12	fg	386	fg	3.2	fg
	2	32	c	1.24	c	189	c	42	c	1860	c	15.5	c
	4	25	d	0.81	d	147	d	34	d	1418	d	11.1	de
	6	12	f	0.53	e	68	f	14	f	519	f	4.4	f
	8	7	gh	0.16	g	33	hi	6	hi	196	ghi	0.9	gh
	10	4	h	0.09	g	20	i	4	i	54	i	0.2	h

[a]Means in the table for each parameter is the interaction effect between seed scarification and seed burial depth of pooled data of two trials.
[b]Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ based on Fisher's protected LSD test.
[c]Seed scarification includes mechanical scarification and no scarification.
[d]Seed burial depth includes six different depths of seed burial: 0, 2, 4, 6, 8, 10 cm.
[e]Emergence indices, EP, SE, EI and ERI were calculated by considering the redweed seeds emerged on each day up to 30 days after sowing.
[f]Seedling vigor indices, SVI I was calculated by considering the emergence percentage and seedling length of redweed and SVI II was calculated by considering the emergence percentage and seedling biomass of redweed.
[g]Abbreviations: EP, emergence percentage; SE, speed of emergence; EI, emergence index; ERI, emergence rate index; SVI I, seedling vigor index I; SVI II, seedling vigor index II.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

Table 2. Seedling parameters of redweed as influenced by seed scarification and seed burial depth.[a,b]

Seed scarification[c]	Seed burial depth[d]	Seedling parameters											
		Shoot length		Root length		Shoot biomass		Root biomass		Seedling length		Seedling biomass	
		----------------------- cm -------------------------				---------- g plant^{-1} -----------				cm		g plant^{-1}	
Mechanical scarification	0	29	b	28	c	0.36	c	0.17	c	58	c	0.53	c
	2	32	a	38	a	0.44	a	0.28	a	70	a	0.72	a
	4	31	a	37	a	0.39	b	0.23	b	68	b	0.62	b
	6	28	c	25	d	0.31	de	0.17	c	53	e	0.47	d
	8	19	f	16	e	0.18	g	0.08	f	35	h	0.26	h
	10	10	h	11	f	0.03	i	0.01	h	20	j	0.04	j
No scarification	0	21	e	27	c	0.29	e	0.11	e	48	f	0.40	f
	2	26	d	32	b	0.32	d	0.16	c	58	c	0.48	d
	4	25	d	31	b	0.30	de	0.14	d	56	d	0.44	e
	6	20	f	24	d	0.26	f	0.10	e	43	g	0.36	g
	8	14	g	16	e	0.10	h	0.04	g	30	i	0.14	i
	10	7	i	6	g	0.03	i	0.01	h	13	k	0.04	j

[a]Means in the table for each parameter of seedling parameters is the interaction effect between seed scarification and seed burial depth of pooled data of two trials.

[b]Means followed by the same letter within a column are not significantly different at $P \leq 0.05$ based on Fisher's protected LSD test.

[c] Seed scarification includes mechanical scarification and no scarification.

[d]Seed burial depth includes six different depths of seed burial:0, 2, 4, 6, 8, 10 cm.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

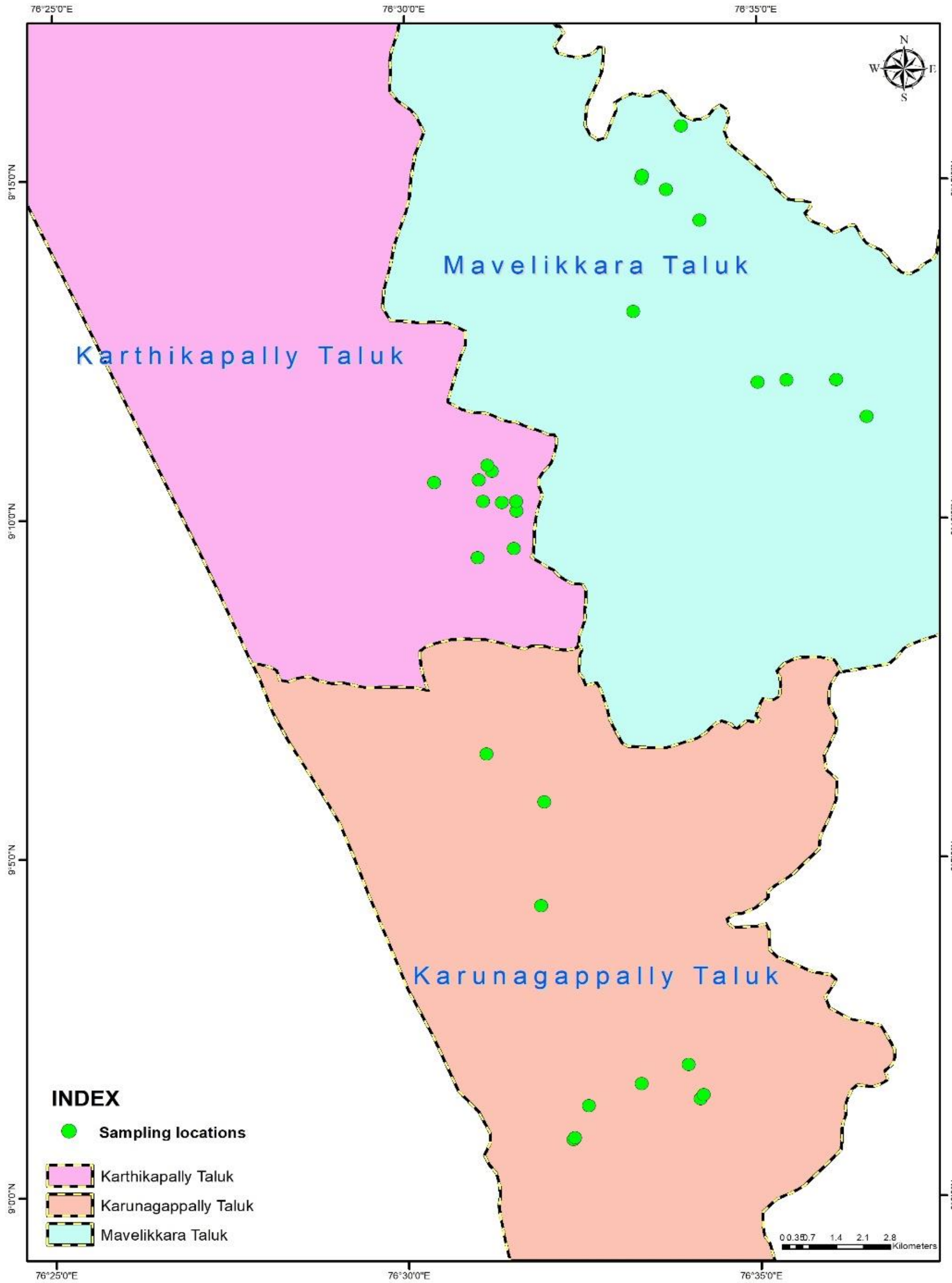

Figure 1. Locations in Karunagapally, Karthikapally and Mavelikkara regions from where redweed seeds were collected.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

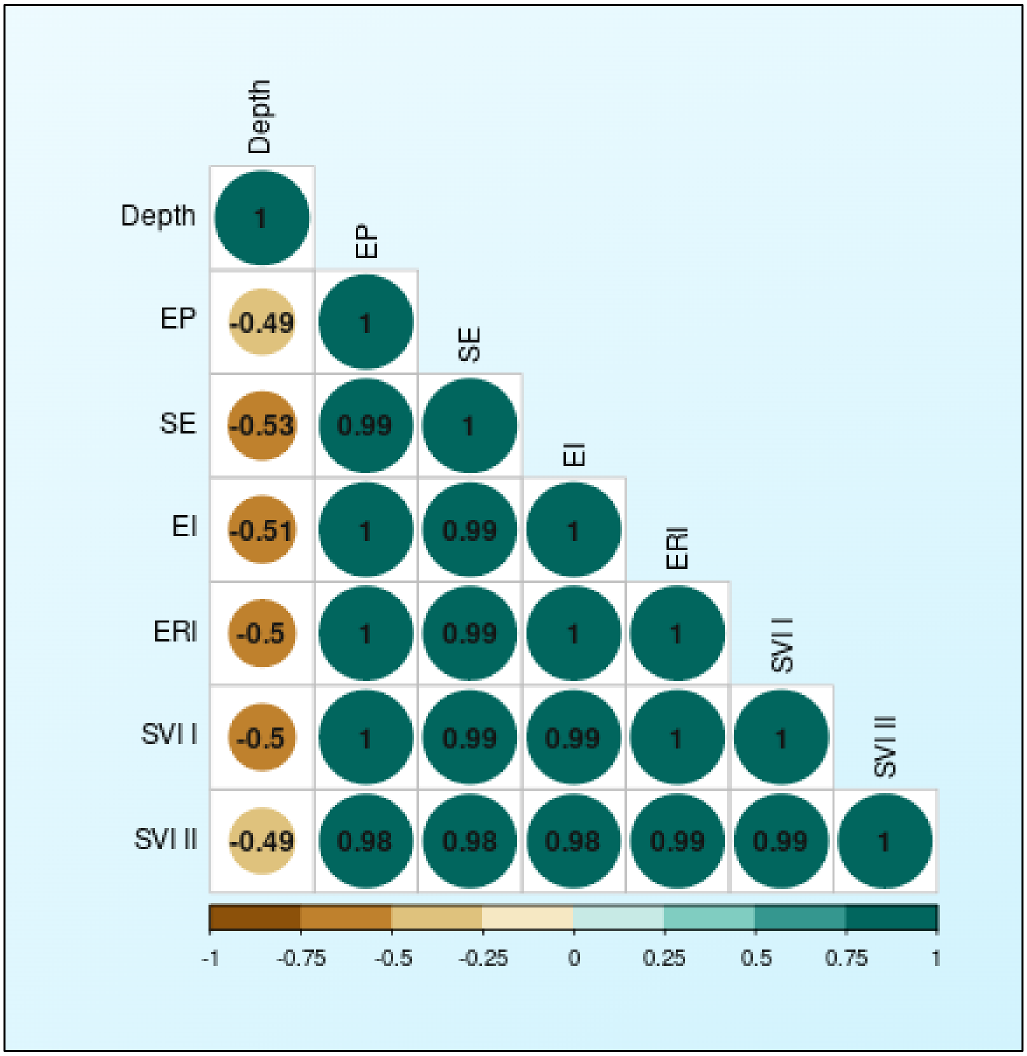

Figure 2. Correlation matrix of seed burial depth, emergence percentage (EP), speed of emergence (SE), emergence index (EI), emergence rate index (ERI), seedling vigor index I (SVI I) and seedling vigor index II (SVI II).

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

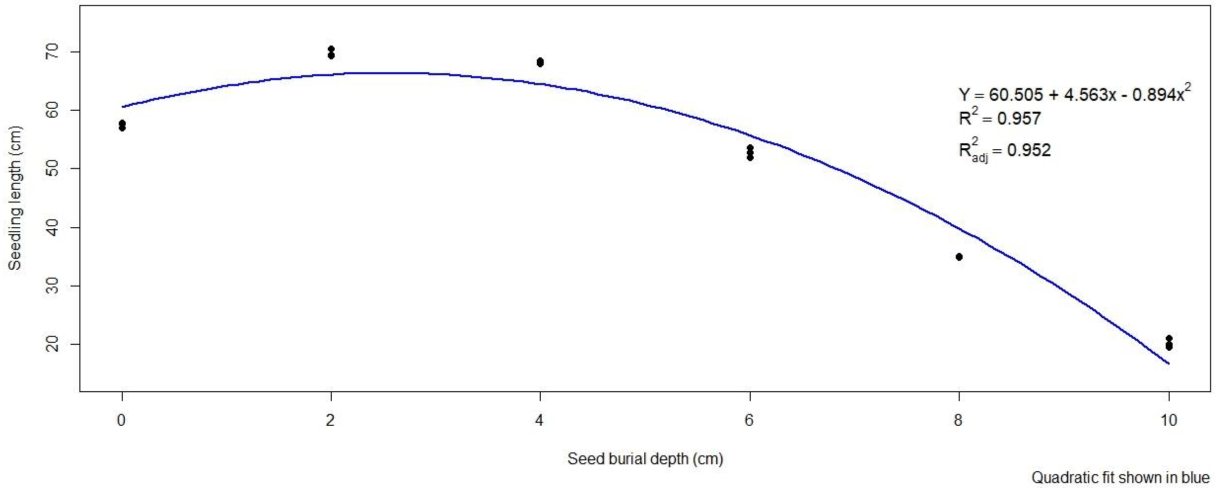

Figure 3. Polynomial regression model depicting the relationship between seed burial depth and seedling length of scarified seeds of redweed.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

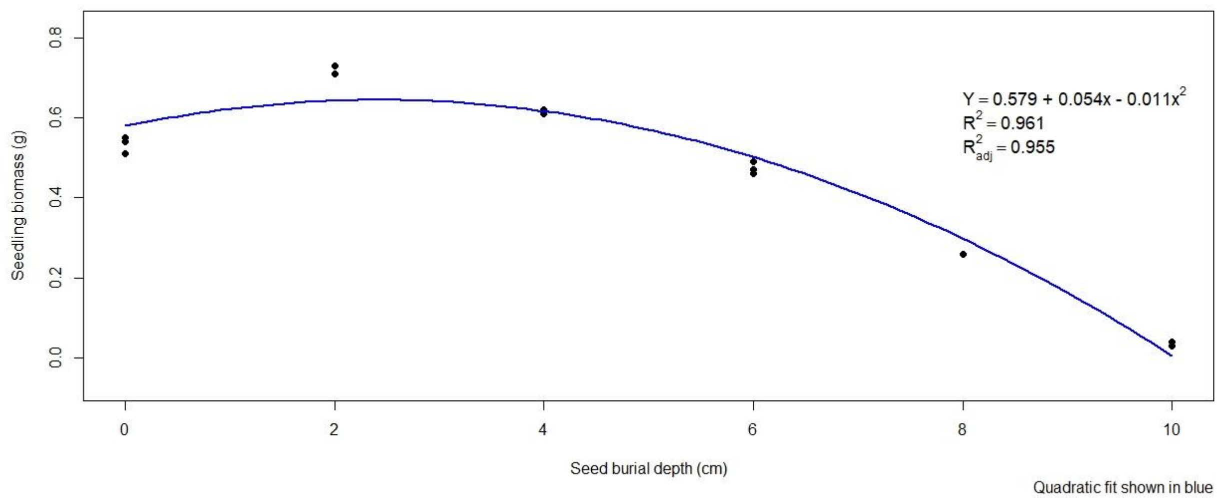

Figure 4. Polynomial regression model depicting the relationship between seed burial depth and seedling biomass of scarified seeds of redweed.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

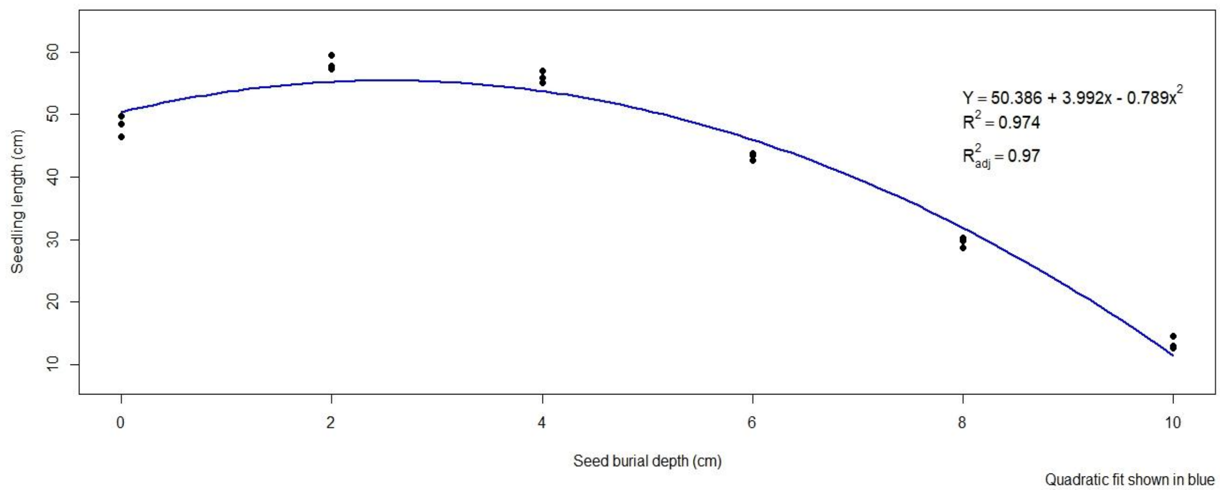

Figure 5. Polynomial regression model depicting the relationship between seed burial depth and seedling length of non-scarified seeds of redweed.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press

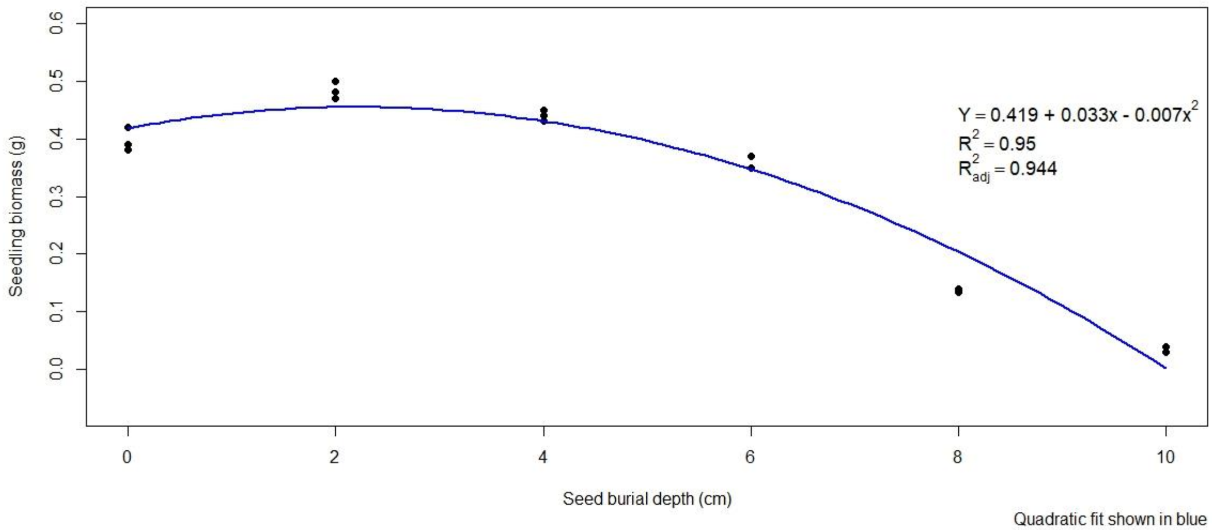

Figure 6. Polynomial regression model depicting the relationship between seed burial depth and seedling biomass of non-scarified seeds of redweed.

https://doi.org/10.1017/wet.2024.108 Published online by Cambridge University Press