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Effect of Seeding Depth and Flooding Duration on the Emergence of Some Rainy Season Weeds

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ABSTRACT

Screen house studies were carried out under controlled conditions during the rainy seasons of 2006 and 2007 at CCS Haryana Agricultural University, Hisar to evaluate the influence of seeding depth and flooding duration on the emergence of *Ammania baccifera, Cyperus alutatus, C. arenarius, C. difformis, C. iria* and *Scirpus roylei*. Seeding depths of 0, 0.5, 1, 2 and 4 cm and flooding durations of 0, 4, 8, 16, 32 and 64 days were maintained with four replicated pots. Maximum emergence was recorded from 0.5 cm and surface (0 cm) which decreased by 44 and 80% at 1 and 2 cm depths compared to 0.5 cm depth and no emergence was recorded from 4 cm or higher depths, data averaged over species. Emergence of *S. roylei* was 80% at 0.5 cm and decreased by 9 and 46% at 1 and 2 cm depths, whereas 63% lower emergence was recorded from 0 cm depth, respectively. Emergence of *A. baccifera*, *C. difformis* and *C. iria* was similar from 0 and 0.5 cm but decreased significantly with increasing depths, whereas *C. arenarius* and *C. alutatus* recorded 20 and 10% lower emergence, respectively, from 0.5 cm compared to surface placed seeds and no emergence was recorded from 2 cm depth. However, 43, 27 and 15% emergence was recorded for *S. roylei*, *A. baccifera* and *C. iria* from 2 cm depth, respectively. Flooding caused significant reduction in the emergence of *C. arenarius* and *C. alutatus*, but had no adverse effect on *S. roylei*. Flooding encouraged emergence of *C. difformis* and *C. iria* as higher emergence was observed with increasing flooding period from 0 to 16 days (d), whereas 16 d flooding caused 100% reduction in the emergence of *C. arenarius*. Conversely, *S. roylei* emergence inhibited without flooding and flooding duration of 16 d or more resulted in >90% emergence. Increased flooding duration was positively correlated with the emergence and growth of all species except *C. arenarius* and *C. alutatus*. A flooding duration of 64 d reduced emergence of *C. difformis* and *C. iria*, but still it was similar to no flooding and their growth was more compared to lower flooding durations. Similarly, *A. baccifera* emergence was 18% lower with 64 d flooding compared to no flooding, but had no adverse effect on plant growth and no inhibition in emergence was observed in *S. roylei* with 64 d flooding. The results indicate susceptibility of *C. arenarius* and to a lower extent of *C. alutatus* to flooding, but emergence and growth of other *Cyperus* spp., *S. roylei* and *A. baccifera* was stimulated by water. The test species behaved differently to moisture levels and seeding depths and this information can be used under different conditions using tillage operations and water management for lowering their menace.

Key words : Weed biology, burial depth, soil moisture, management strategy

INTRODUCTION

Weed problems are perennial and continue to evolve over the time; knowledge of weed biology is essential to strengthen practical weed management in an integrated system. Even in the modern era of herbicidal weed management, weed problems still persist rather complicated due to shift in weed flora and evolution of resistant biotypes. Understanding and exploiting knowledge on weed biology remains vital for developing effective weed management approaches. Field preparation is the first step that prompts weed emergence. Germination and emergence of weed species is influenced by several factors, including seed burial depth, soil moisture, temperature and light (Blackshaw, 1990; Bewly and Black, 1994; Baskin and Baskin, 1998; Benvenuti *et al*., 2001; Singh *et al*., 2007; Singh and Punia, 2008; Chauhan and Johnson, 2010).

Seeding depth not only affects the emergence of weed species; weed dormancy which affects germination and regulated by light, temperature and moisture, is governed by burial depth (Richard and Street, 1984; Van Assche and Vanlerberghe, 1989; Baskin and Baskin, 1994). Seed size and weight play a significant role as small seeds buried deeper in soil either fail to emerge or are meagre enough to offer stiff competition to crops (Benvenuti *et al*., 2001; Tamado *et al*., 2002; Singh *et al*., 2007). Deep ploughing (soil inversion) can bury weed seeds to restrict their emergence, but this may vary with weed species.

During the last several decades, farming technologies have transformed dramatically. Among these soil tillage and herbicides are the most prominent changes to substantially lower energy use and improve weed management. Reduced or zero tillage, use or pre-emergence herbicides and agronomic practices in response to weed ecology knowledge have improved our chances for successful weed management in a sustainable manner. However, zero/minimum tillage has also disturbed the seed size and shape relationship with vertical distribution of weeds in soil horizon (Froud-Willams, 1988). In the pursuit of more sustainable approaches, knowledge of weed ecology is most desired.

Global climatic change, either directly or indirectly, induces changes in land use pattern and cropping system. Scarcity and growing competition for fresh water resources also reduce its availability for irrigation and rice cultivation will be affected by this phenomenon. Weeds may behave differently to an alteration to moisture regimes and need additional resources for effective management. Germination is initiated when the water content of the embryo is adequate to support biochemical events. Soil moisture stress and flooding, both can inhibit germination process; the effect varies in different plant species. Anaerobic conditions by flooding can cause metabolic changes affecting germination (Gould and Rees, 1964; Ehrenshaft and Brambl, 1990). Water management is a major component of any weed control programme, whether a herbicide is used or not. The timing, duration and depth of flooding govern the specific nature of weed suppression by water. Water depth can be used to control many weeds, but there are a number of species that are relatively unaffected by water depth under rice culture. Weeds of rice fields are unique in their capacity to survive and regenerate under prolonged periods of flooding, while terrestrial weed populations decrease as water depth increases (McIntyre, 1985). Keeping the field flooded after planting will kill some weeds and will slow the growth of others.

Continuous use of grass only herbicides in rice resulted in the emergence of broadleaf weeds like *Ammania* sp., whereas some sedges started to defy herbicides. These sedges along with other weeds would be a challenge while shifting from transplanting to direct seeded upland rice cultivation. Knowledge of seed behaviour to seeding depth and moisture can be utilized in manipulating tillage operations and water scheduling in the management system. *C. alutatus* Kern. is an annual sedge, 5-40 cm height infesting cotton, millets and other rainy season crops and is very competitive under low to medium rainfall conditions in desert, arid brown and sierozem soils. *C. arenarius* Retz., reported under sandy soils in India, Vietnam, Sri Lanka, Australia and S. Africa, is a perennial weed of 6-30 cm height with long creeping rhizome. In north-west Haryana this is a major weed in sandy soils with deep rooting system. *C. difformis* L. is annual sedge, erect, smooth, densely tufted that can grow 75 cm tall and has been reported as a major weed of rice in 46 countries in southern Europe, Asia as well as central and north America (Holm *et al*., 1977). This weed is well adapted to moist lowland soils or flooded areas; normally propagated by seeds and is a heavy seed producer and can complete one life cycle in about 30 days. Through high seed production and short life cycle, this weed can spread rapidly to become a dominant weed in a rice field. Earlier this was easily controlled by post-emergence herbicides, but some biotypes have evolved resistance to ALS inhibitor herbicides in Australia, Brazil, Italy, S. Korea, Spain and USA (Heap, 2010). *C. iria* L. is a tufted annual herb, 10-70 cm tall, which thrives in wetland rice, dryland annual crops and plantation crops. It multiplies rapidly and can produce 3,000-5,000 seeds per plant; seedlings emerge immediately after crop is sown which flowers within a month and can establish second generation in the same season. *C. iria* is an important and widespread weed in Asia (China, Taiwan, Japan, Korea, Bangladesh, Cambodia, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam and also in Australia, Fiji, Swaziland and West Africa. *Scirpus roylei* (Nees) Parker, a slender sedge with clustered besom-like stems of about 30-50 cm height, growing in shallow water and swampy grassland and rice fields of several African and Asian countries, where it is a major weed under irrigated conditions. *A. baccifera* L. is an erect, branched, smooth, slender, annual broadleaf herb, found in open, damp and waste places. It is more or less purplish herb 10-50 cm in height and prolific seed producer that is spreading fast in rice culture and also becoming a major weed in other rainy season crops in India. *A. baccifera* is widely spread to several continents and is a major weed of rice.

The common sedges infesting the fields are *C. alutatus*, *C. arenarius*, *C. difformis*, *C. iria* and *Scirpus roylei*. The objective of this study was to evaluate the effect of seeding depth and flooding duration on emergence and growth of these weed species.

MATERIALS AND METHODS

Seeds of *A. baccifera*, *C. alutatus*, *C. arenarius*, *C. difformis*, *C. iria* and *S. roylei* were collected from rice, cotton and millet fields from Haryana state during 2005 and stored under room temperature in the laboratory until used in the present study.

Effect on Seeding Depth on Emergence

Screen house experiments were conducted at CCS Haryana Agricultural University, Hisar during rainy seasons of 2006 and 2007 (repeat) using plastic pots of 25 cm height and top diameter with 10 kg soil capacity. Field soil collected from non-experimental area of Agronomy Department was mixed in 2 : 1 : 1 ratio of field soil, dunal sand and vermicompost. The soil was sandy loam in texture, low in organic carbon and available N, medium in P_2O_5 and high in K_2O with a pH of 8.3. Twenty-five seeds of each species were placed either at surface (0 cm), 0.5, 1, 2 or 4 cm depth with four replicate pots for each species. During the first year seed burial depths of 6 and 8 cm were also maintained, but no emergence was recorded from these depths and these treatments were not repeated in the second year. Pots were watered daily by sprinkler after seeding for three weeks and later on as and when required. Emergence was recorded periodically and final data were recorded 80 days after sowing (DAS).

Effect of Flooding Duration on Emergence

For flooding duration studies during 2006 and 2007, plastic pots of medium size (20 cm height and top diameter containing 7 kg soil) were filled with soil similar to seeding depth studies. Seeding was done at 0.5 cm depth with 25 seeds of each species with four replications for each species and flooding durations and pots were filled with water except for 0 day. Normal watering was done for no flooding treatment, whereas a 2-3 cm layer of water was always maintained in pots for 4, 8, 16, 32 and 64 days. After the specified flooding durations, holes were made at the bottom of the pots to drain water. Periodic observations were recorded on emergence and growth.

Both experiments were initiated on 3 August 2006 and 20 August 2007. Data on number of plants emerged per pot were converted for per cent emergence and pooled data from two years' observations were subjected to ANOVA using SPSS Software. One-way ANOVA was done to separate means with Student-Newman-Keuls test. Data were regressed to second order polynomial and trend lines fitted to graphs for seeding depth and flooding durations. Per cent emergence data are presented in figures with standard error of means.

RESULTS AND DISCUSSION

Effect of Seeding Depth

When averaged over species maximum emergence of 70% was recorded from 0.5 cm depth which was statistically similar to surface (0 cm). Increasing the seeding depths to 1 and 2 cm recorded only 39 and 14% emergence and no emergence was observed from 4 cm depth.

A. baccifera had 70 and 75% emergence from surface and 0.5 cm depth, respectively, but it was reduced by 20 and 64% over 0.5 cm with increasing depths of 1 and 2 cm (Fig. 1). The effect of seeding depth on emergence was significant as described by the quadratic equation, $y = -5.595x^2 + 14.405x + 65$ with $R^2 = 0.98$.

Emergence of *C. alutatus* was maximum from surface (70%), but decreased significantly with increasing depths and no emergence was recorded beyond 1 cm depth as derived from quadratic equation, $y = 1.905x^2 - 31.762x + 106$, $R^2 = 0.93$ (Fig. 1). Similarly, *C. arenarius* had no emergence from 2 cm or higher depths and even 0.5 cm depth recorded 20% lower emergence compared to surface (Fig. 1). The data were regressed to quadratic model, $y = 3.452x^2 - 37.548x + 98.667$, $R^2 = 0.94$ and contribution of depth was significant towards emergence.

C. iria had higher emergence compared to *C. difformis*, but emergence was statistically similar from surface and 0.5 cm depth (Fig. 2). Emergence of *C. difformis* was drastically reduced from 73 to 27% from 0.5 to 1 cm depth and no emergence was recorded

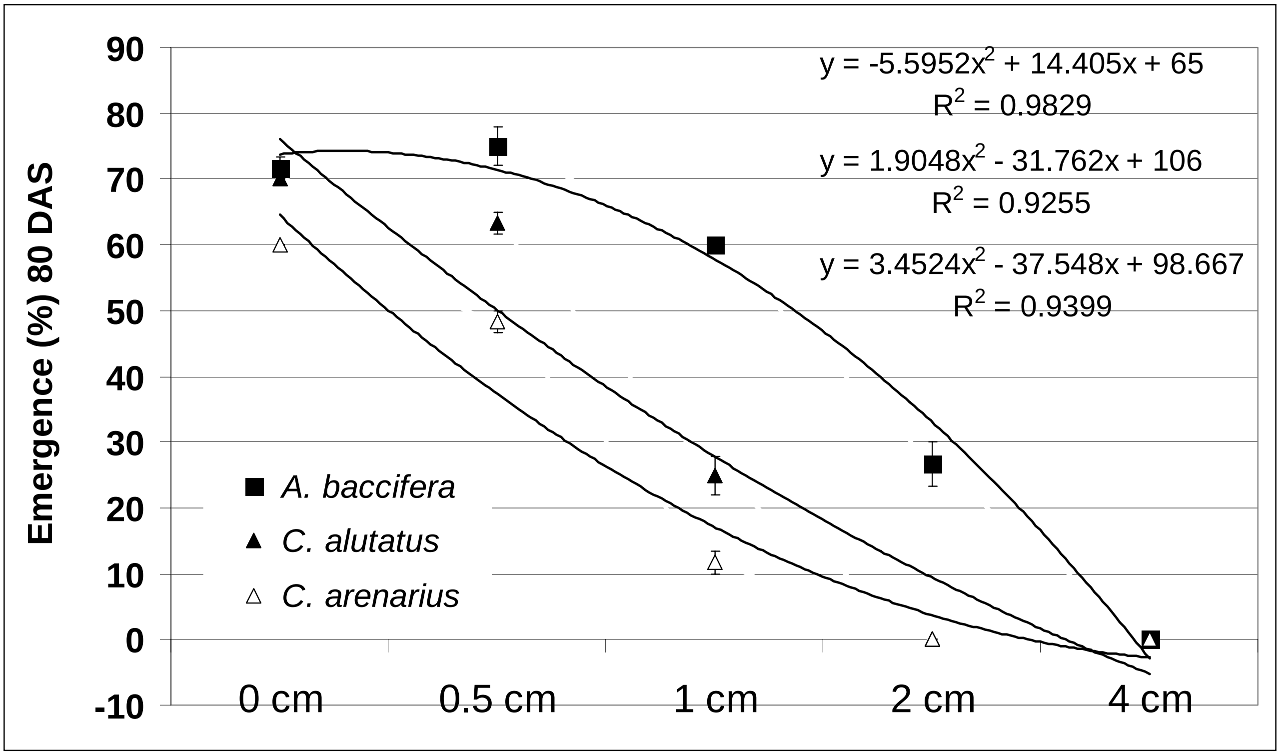

Fig. 1. Effect of seeding depth on the emergence of *A. baccifera*, *C. alutatus* and *C. arenarius* (bars indicate SEm).

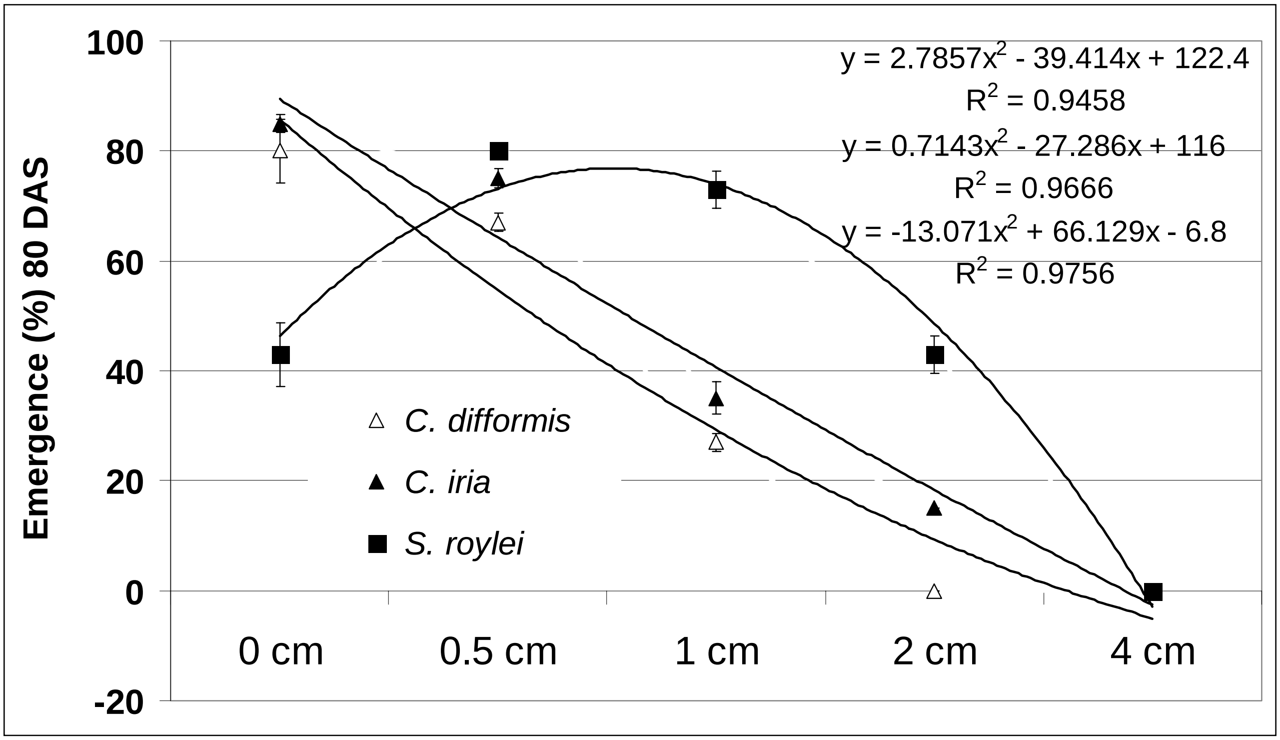

Fig. 2. Effect of seeding depth on the emergence of *C. difformis*, *C. iria* and *S. roylei* (bars indicate SEm).

beyond 1 cm depth as explained by quadratic equation and best fit line, $y = 2.786x^2 - 39.414x + 122.4$, $R^2 = 0.95$. *C. iria* on the other hand was able to emerge from 2 cm depth, though emergence was reduced by 82%. The emergence data were regressed to second order polynomial model, $y = 0.714x^2 - 27.286x + 116$, with best fit line and value of $R^2 = 0.97$. Emergence of *S. roylei* was minimum from surface followed by 2 cm depth (Fig. 2). Maximum emergence of *S. roylei* was from 0.5 cm depth which decreased significantly by increasing depth of 1 cm and no emergence was recorded from 4 cm depth. The quadratic regression equation used to describe emergence was highly significant, $y = -13.07x^2 + 66.129x - 6.8$, $R^2 = 0.98$.

The emergence pattern of *C. difformis* and *C. iria* confirms the earlier results of Chauhan and Johnson (2009). Ismail *et al*. (2007) reported no germination of *C. difformis* in the dark and found maximum emergence from 0 cm depth and no emergence from 1 cm onwards. Light may be an inhibitory factor when seed is buried at deeper depths for photoblastic weed seeds.

Gardarin *et al*. (2010) reported that shoot growth rate, maximal shoot and radicle lengths were positively correlated with seed mass. Singh and Punia (2008) reported significant variations in the emergence of *Rumex dentatus* and *R. spinosus* both having large seed size. These large seeded weeds had maximum emergence from 1 cm depth, but beyond 4 cm no emergence of *R. dentatus* was observed, whereas *R. spinosus* could emerge from deeper depths. Harrison *et al*. (2007) studied emergence of *Ambrosia trifida* seed of two sizes (<4.8 and >6.6 mm dia) from 0, 5, 10 and 20 cm depths over several growing seasons and found that maximum emergence occurred from 5 cm depth, but emergence probability of large seed was 2.6 and 3.3 times more from 5 and 10 cm depths, respectively, over small size seed and seed survival was inversely proportional to seeding depths. Seed buried at 20 cm depth had 19% viability after four seasons compared to 0 when placed at surface.

Singh *et al*. (2007) studied the emergence pattern of *Amaranthus retroflexus*, *Bidens pilosa*, *Sida spinosa*, *Desmodium tortuosum* and *Senna obtusifolia* under Florida conditions and found that irrespective of seed size, emergence was reduced with increasing depths and most of the species had maximum emergence from 0.5 cm depth. *Digitaria sanguinalis* and *Poa annua* emergence was restricted at depths > 2 cm, while *Panicum dichotomiflorum* was not, whereas small-seeded broadleaf species, cudweed (*Gnaphalium* sp.) and toad rush (*Juncus bufonius*) did not emerge from depths >1 cm (James *et al*., 2002). Grundy *et al*. (2003) observed that large seeded *Veronica hederifolia* emerged from 8 cm depth compared to small seeded weeds, *Tripleurospermum inodorum* and *Veronica arvensis* whose emergence was significantly reduced beyond 1 cm depth. However, they found the relationship between seed size and emergence depth complex as under optimum conditions some weeds species viz., *Stellaria media* and *Chenopodium album*, due to physical reserves could emerge from a wider range of burial depths than normally observed in the field, suggesting an ability to exploit opportunities when they occur. Lower emergence of *S. roylei* (Fig. 2) from surface unlike other sedges could be due to moisture stress. *Malva parviflora*, which is a serious weed of wheat under rice-wheat rotations, has fewer emergences from surface compared to 1 or 2 cm depths (Singh and Punia, 2008).

Tillage has a strong impact on weed emergence by burying weed seeds in the soil and modifying soil structure. Its influence can vary according to seed and seedling characteristics. Seedling mortality increased with increasing obstacle size for all species; but it was greater for monocots than for dicots and decreased with the shoot diameter. Weed seed depth and soil structure influence emergence of weed species differently, depending on seed mass, shoot diameter and taxa.

Effect of Flooding Duration

Flooding duration had a significant effect on the emergence, though the effect varied with weed species. Emergence of *A. baccifera* was only 20 and 40% with 0 and 4 d flooding, respectively, when recorded 35 DAS compared to > 90% with 8 and 16 d flooding. The same was reflected in growth and final emergence 75 DAS (Plate, top left on cover page). Emergence of *A. baccifera* was not affected by 16 d flooding (92%) as maximum emergence was recorded with 8 d flooding (Fig. 3). *A. baccifera* seeds were able to emerge from standing water and increased flooding duration resulted in increased plant height, though 11 and 18% lower emergence was recorded with 32 and 64 d flooding compared to no flooding. The quadratic regression equation used to describe seedling emergence which was highly significant, $y=-1.845x^2+9.2024x +84.667$, $R^2 = 0.95$.

Maximum emergence of *C. alutatus* was recorded with no flooding which was similar to 4 d flooding, but increasing the flooding period reduced the emergence significantly and no emergence was recorded with 32 d flooding (Fig. 3). A flooding period of 8 and 16 d caused 22 and 80% reduction in emergence of *C. alutatus*. The contribution of flooding duration was highly significant on emergence as explained by quadratic equation with best fit line, $y=0.208x^2-18.982x+98.833$, $R^2 = 0.91$.

Among the sedges, maximum inhibition in the emergence was recorded with *C. arenarius* (Fig. 3). A flooding period of 4 and 8 d resulted in 23 and 81% reduced emergence, respectively, and no emergence was observed with higher flooding durations (Fig. 3). The quadratic model, $y = 3.958x^2 - 41.232x+104.83$, $R^2 = 0.96$ best describes the regression equation.

C. difformis emergence significantly increased with 8 or 16 d flooding compared to 0 or 4 d flooding (Fig. 4). An 8 d flooding resulted in better emergence and growth as is visible in inset photo (Lower left on the cover page, 25 DAS). A flooding period of 32 and 64 d caused only 11 and 14% reduction, respectively, in its emergence compared to 8 or 16 d flooding. The data were regressed to second order polynomial model, $y = -2.262x^2 + 16.595x + 57.333$, $R^2 = 0.78$.

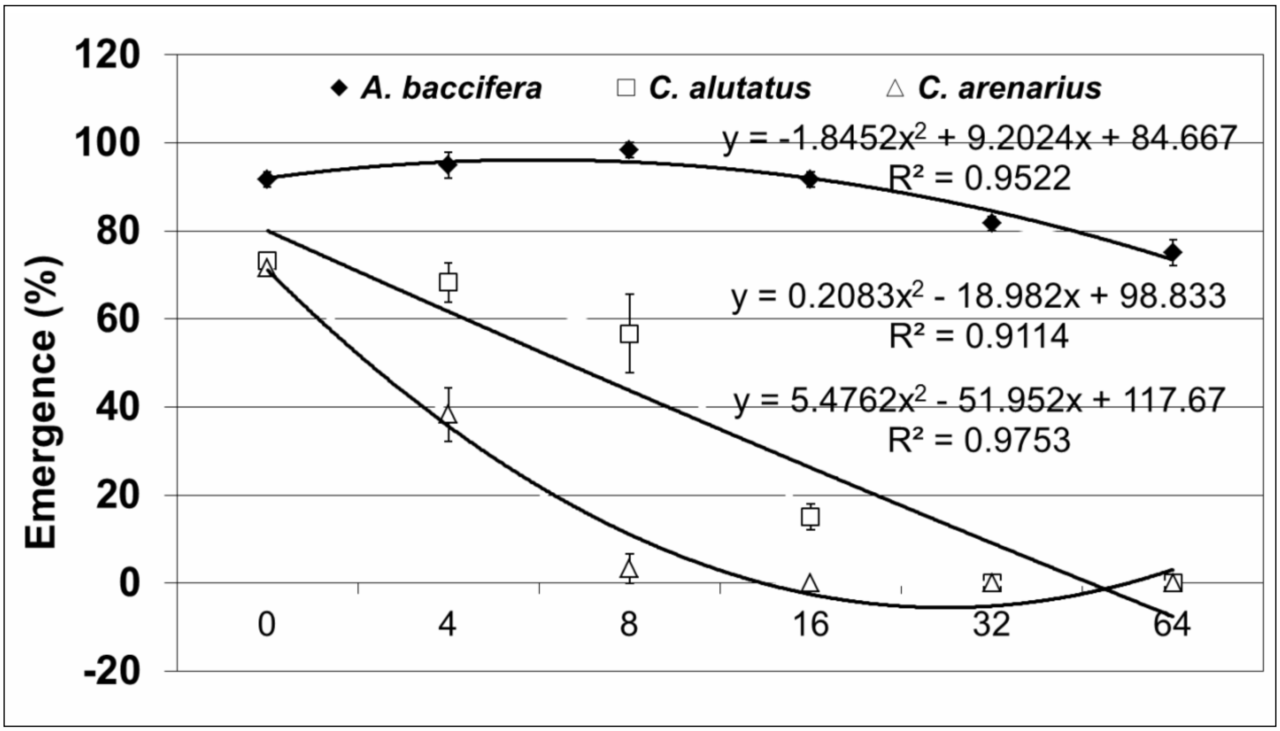

Fig. 3. Effect of flooding duration on the emergence of *A. baccifera*, *C. alutatus* and *C. arenarius* (bars indicate SEm).

C. iria had more emergence than *C. difformis* with increased moisture, though the trend was similar (Fig. 4). Emergence peaked with 8 d flooding which was 20% higher compared to no flooding or 64 d flooding. Increasing the flooding period beyond 32 d resulted in decreased emergence but there was no decrease in growth under flooded conditions and seed emerged in standing water. The polynomial model, $y=-2.589x^2 +16.887x+66.833$, $R^2 = 0.78$ describes the best fit regression.

Emergence of *S. roylei* was inhibited without flooding and seedling emergence increased with increased flooding durations (Fig. 4). Increased emergence was also associated with better growth with increased flooded duration. Emergence was poor till 16 d flooding and peaked at 32 d flooding. A flooding period of 64 d had no adverse effect on the emergence and growth of *S. roylei*. The data were regressed to polynomial model, $y= -3.244x^2 + 42.899x-38.167$, $R^2 = 0.96$.

Soil moisture affects the timing of weed emergence and the number of weed seedlings emerging. *S. roylei* emergence increased with increased flooding

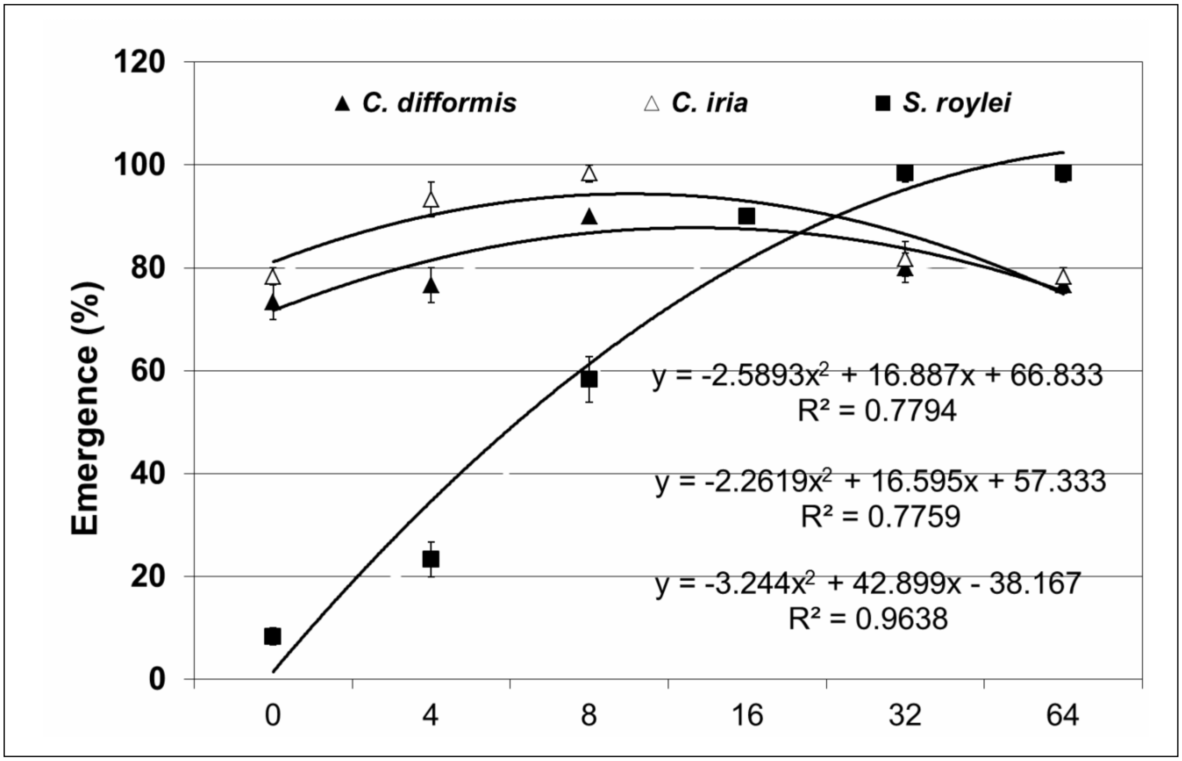

Fig. 4. Effect of flooding duration on the emergence of *C. difformis*, *C. iria* and *S. roylei* (bars indicate SEm).

duration (Fig. 4). Higher germination of *C. difformis* occurred at 100% soil moisture content but decreased as the soil moisture content decreased (Ismail *et al.*, 2007). The highest percentage emergence was observed at saturated water conditions of the soil surface and it decreased with increased submergence. However, in the present study, decrease in emergence was observed only after prolonged flooding (Fig. 4). Effect of continuous or intermittent flooding and depth of water level had significant effect on weed seed emergence. Deep flooding was required to suppress *C. difformis* (Chauhan and Johnson, 2009) as shallow or intermittent flooding was not found effective. *C. difformis* is not drought tolerant and requires standing water for germination. The moist conditions enhance early panicle emergence and anthesis compared to weeds kept under a constant level of water (Ravindran *et al.*, 1999). The present studies also reveal better emergence and growth of *C. difformis* (Plate C on title page and Fig. 4) with flooding compared to no flooding. This lesser time required for emergence, achieve maximum biomass and advances the reproductive stage under standing water and could be exploited for its management.

Water constitutes a powerful selective agent for weed management in lowland rice (Mortimer and Hill, 1999; Caton *et al.*, 2002) and flooding is a key factor influencing the severity of weed competition and the effectiveness of herbicides (Kim *et al.*, 2001). Since rice is more tolerant to flooding than many weed species and this differential response can be utilized for effective weed management, except for weeds like *S. roylei*. A 4 to 8 d flooding caused significant reduction in the emergence of *C. arenarius* and *C. alutatus*, respectively (Fig 3), but had no adverse effect on *S. roylei* (Fig. 4). Singh and Punia (2008) reported greater emergence of *R. dentatus* with flooding compared to *R. spinosus* which was very sensitive to flooding. Also flooding enhanced emergence of *M. parviflora* and highest emergence was recorded with 80 d flooding. Similarly, *A. retroflexus* was able to emerge with 32 d flooding, whereas other weeds could not tolerate 8 d flooding (Singh *et al.*, 2007).

Flooding can inhibit germination and growth of a number of weed species; however, the response of weeds to flooding varies from species to species, timing, duration and depth of flooding (Civico and Moody, 1979; Hill *et al.*, 2001). *C. iria*, *Echinochloa colona*, *E. crus-galli*, *E. glabrescens* and *Fimbristylis miliacea* can be controlled by flooding (Civico and Moody, 1979; Diop and Moody, 1984; Kent and Johnson, 2001; Smith and Fox, 1973), whereas *Monochoria vaginalis* and *Sphenoclea zeylanica* could tolerate flooding (Pons, 1982; Kent and Johnson, 2001).

Chauhan and Johnson (2010) reported that 28 d continuous flooding of 2 cm reduced emergence of *C. difformis*, *C. iria*, *F. miliacea*, *Leptochloa chinensis* and *Ludwigia hyssopifolia*. However, intermittent (two days out of seven days for 28 days) flooding was effective only with 10 cm flooding. They also reported that flooding caused significant reduction in weeds dry matter accumulation; however, in the present study, a 2-3 cm standing water reduced emergence only after 32 d flooding, but no significant reduction in growth was observed for *C. difformis*, *C. iria* and *S. roylei*.

A flooding depth of 10 cm for more than two weeks was required to reduce emergence of *F. miliacea* (Begum *et al*., 2006), whereas *L. hyssopifolia* required only 2.5 cm flooding depth (Pons, 1982), on the other hand germination of *M. vaginalis* seeds was unaffected even by 20 cm water depth. Sahid and Hossain (1995) reported that flooding depth of 4 cm was able to reduce the emergence of *C. iria*, *E. colona*, *E. crus-galli* and *L. hyssopifolia* compared with saturated soil. Phogat and Pandey (1998) reported that in the presence of herbicides, weed density of *C. iria*, *E. crus-galli*, *Eclipta prostrata* and *L. chinensis* was not significantly affected by continuous submergence, soil saturation and alternate wetting and drying, whereas Bhagat *et al*. (1999) concluded that continuous shallow flooding in rice throughout the growing season suppressed many weed seeds compared to saturated soil conditions.

The present study reveals that seed burial depth significantly affected the emergence of *A. baccifera*, *C. alutatus*, *C. arenarius*, *C. difformis*, *C. iria* and *S. roylei* when placed below 2 cm depth and this can be achieved by tillage operations, except in zero tillage. Maximum emergence of these species was observed from surface followed by 0.5 cm depth and this information can be utilized in exhausting soil seed bank by bringing seeds on surface and allowing their predation and killing emerged weeds by herbicides (zero tillage) or tillage operations. The importance of weed biology studies is more apparent if their outcomes are effectively linked to practical weed management (Van Acker, 2009). Similarly, manipulation in moisture regimes can be put to use to favour crops and suppress emergence of sedges and their growth, though the effect varies with species.

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