**Barnyardgrass life cycle**



A schematic representation of the model for simulating the evolution of glyphosate-resistance in barnyardgrass is shown above. The life cycle consists of three distinct stages: dormant seeds in the soil seedbank (), emerged seedlings (), and mature plants (). Seedbank comprises of different genotypes (susceptible, SS; heterozygous resistant, RS; and homozygous resistant, RR) present at Hardy-Weinberg equilibrium frequency levels. Model simulates the transition of life-history stages from seed at time (immediately prior to seedling emergence in late spring) to seed at the next time step +1. Arrows represent the transition of different genotypes from the th stage to theth stage and the coefficient for each transition is given by the function associated with each set of arrows. A proportion of seeds from the dormant seedbank breaks dormancy and germinates in the spring (), while the rest remain dormant in the seedbank; the remnant seedbank size is determined by the level of annual seedbank loss (). Seedling emergence occurs in several cohorts, thus transitions are calculated for each cohort. Seedling emergence proportion for the th cohort () is influenced by the amount of growing degree days (GDDs) accumulated during the time window corresponding to each cohort in a given year. Efficacy of different management interventions () and density-dependent seedling survival () determine the number of individuals transitioning to the mature plant stage. Density-dependent fecundity () and proportional reduction in fecundity in response to delayed emergence in crop () influence total seed output per unit area for each cohort. Total viable seed output is dependent upon the viability of freshly produced seeds (). Among the total seeds produced, the proportion of seeds pertaining to each of the three genotypes is determined by the level of outcrossing and mode of inheritance of resistance. The amount of viable seeds added to the active seedbank, however, is governed by the level of post-dispersal seed loss (), which include herbivory, microbial decay, and loss in viability. It is an open-system model wherein propagule immigration () and emigration () occur at pre-defined rates.

The model is described as follows,

 (1)

where the state vector *,* the density of seeds in the soil seedbank at time , is the state vector at the next time step and represents the various transition coefficients that determine the transition from seed to seed. In the context of this paper, represents the time point immediately prior to seedling emergence in late spring.

The transition from seeds in the seedbank () to emerged seedlings () for each genotype (SS, RS or RR) for the th cohort is given by,

 = \* (2)

where is the annual emergence proportion, and is the seedling emergence proportion for the th cohort. The transition from seedlings () to mature plants () is described as,

 = \* (3)

where is the efficacy of different management options and is the density-dependent survival of barnyardgrass seedlings. The following equation represents the transition from mature plants () to seedbank population ().

 = (4)

where is the density-dependent fecundity for the th cohort, is the proportional reduction in fecundity in response to delayed emergence in cotton. The total number of seeds produced is the summation of seed output for all (=1 to 7) cohorts. The final number of viable seeds added to the seedbank at the end of each cycle is dependent on the viability of the freshly produced seeds () and on subsequent seed loss due to herbivory, decay and loss in viability () prior to replenishing the seedbank.

Several sub-models were used to sufficiently describe complex transition coefficients, which include emergence proportion for the th cohort (), density-dependent seedling survival () and fecundity () for the th cohort and proportional reduction in fecundity in response to delayed emergence in crop (). Seedling emergence proportion for each cohort as percent of total recruitment was predicted using a four-parameter Weibull function (described in Bagavathiannan et al. 2011) as follows,

 (5)

where is the percent emergence, is the upper asymptote, is the rate of increase, is the emergence timing (GDDs), is the time of first emergence, and is a curve shape parameter. A base soil temperature for barnyardgrass emergence of 9.7 C was used to calculate GDDs (Wiese and Binning 1987). Soil temperatures were simulated based on the air temperature and precipitation data, using the STM2 model (Spokas and Forcella 2009). Twenty-five-year historical weather data for Blytheville, West Memphis and Monticello obtained from Weather Underground® (www.wunderground.com) were used to predict barnyardgrass emergence in these regions. The 75 site-years were randomly chosen for each simulation with annual variation among sites.

Barnyardgrass seedlings typically respond to inter- and intra-specific density. Bagavathiannan et al. (2011c) described density-dependent survival and fecundity of barnyardgrass in wide-row soybean in Arkansas and the data from this study were used for establishing density-dependent relationships in the model, as follows. The effect of density on the survival of barnyardgrass was regressed using a modified single, three-parameter exponential decay function,

 (6)

where is the number of seedlings survived at a given density, is the exponent, is the density of barnyardgrass and , and are the fitted constants (see Table 1 for fitted parameter values).

The effect of density on seed production of barnyardgrass was sufficiently described using a double, five-parameter exponential decay model,

 (7)

where is the fecundity of barnyardgrass at a given density, is the exponent, is the density of barnyardgrass and , *a*, , and are the fitted constants. The sub-model for barnyardgrass seed production potential with respect to time of emergence in cotton was described using a logarithmic function,

 (8)

where is the predicted variable (seeds plant-1), represents the reproductive potential of barnyardgrass when it emerges with the crop, is the exponent, is a fitted constant and is the time of barnyardgrass emergence. Additionally, a population genetics sub-model was used to represent outcrossing and inheritance of resistance.

References

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