Modeling Weedy Sorghum Population Dynamics in a Stochastic Herbicide-Tolerant Sorghum Cropping System

Rodrigo Werle, Brigitte Tenhumberg, and John L. Lindquist
University of Nebraska-Lincoln, Lincoln, Nebraska

Introduction

- Traditional breeding technology is currently being used to develop grain sorghum germplasm that will be tolerant to acetolactate synthase (ALS)-inhibiting herbicides.
- This technology (Inzen, DuPont) has the potential to improve sorghum production by allowing for the postemergence control of traditionally hard-to-control grasses.
- However, grain sorghum and shattercane can interbreed and introduced traits such as herbicide tolerance could increase the invasiveness of the weedy relative. Moreover, ALS-resistance in shattercane populations has been reported, indicating that over-reliance on ALS-chemistry may also select for resistant biotypes.

Objective

The objective of this research was to develop a simulation model to assess management options to mitigate risks of ALS-resistance evolution in shattercane populations in US sorghum production areas.

Model Description

- ✓ The model assumes that a single major gene confers resistance and gene frequencies change according to the Hardy-Weinberg ratios.
- ✓ The model was constructed as a stage-structured (seedbank [SB], plants [P]) matrix model with annual time steps.
- ✓ The parameter values used in the model were obtained from our research, the literature, and expert opinion (Tables 1 and 2).
- ✓ The model explicitly considered gene flow from sorghum to shattercane populations.

Population Projection Equation

$$N_{t+1} = \mathbf{R}_{t+1}\mathbf{H}_t\mathbf{F}_t N_t$$

- ✓ where N = population vector (seed bank [SB] and plants [P] of each genotype [RR, RS and SS] at flowering), **R** = recruitment matrix, **H** = mating matrix (Hardy-Weinberg), **F** = fecundity matrix, and t indicates the year.

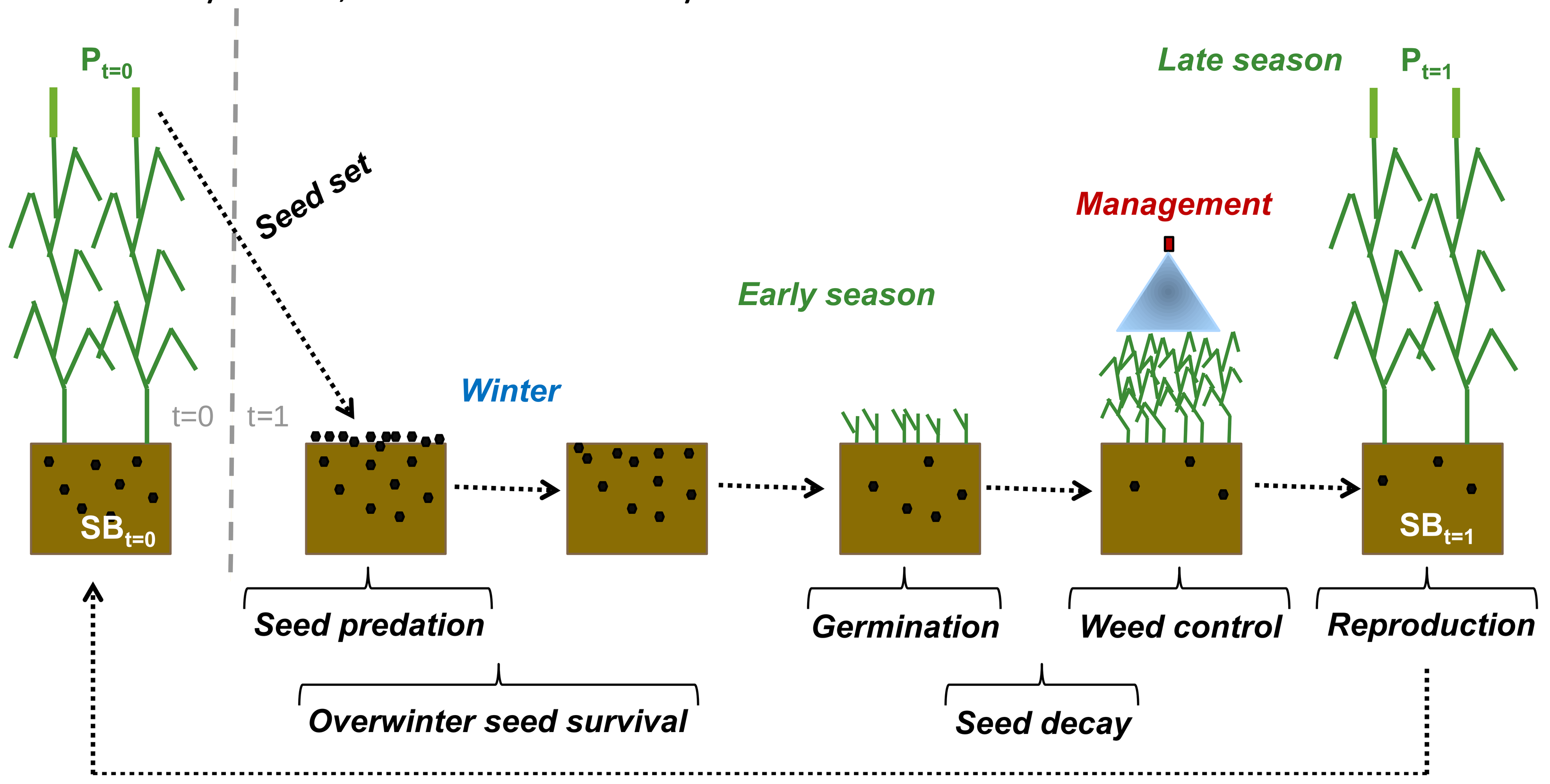

Figure 1: Overview of the simulation model indicating the sequence of events that shattercane individuals go through in the model. Gray dashed line indicates population census.

Crop to Weed Gene Flow

- ✓ To account for gene flow, the frequency of the resistant allele amongst newly produced individuals (p_{t+1}) used by the mating matrix (H) in the generation after Inzen or conventional sorghum is planted was calculated as[1]:

$$p_{t+1} = p_t\left(1-g\right) + g\left(\frac{p_t + p_{crop}}{2}\right)$$

- ✓ where p_t is the frequency of the resistant allele amongst established shattercane plants in a population at time t, g is gene flow from crop to weed (g=0.16)[2], and p_{crop} is the frequency of the resistant allele in the crop. Gene flow only takes place during Inzen (p_{crop}=1) or conventional sorghum (p_{crop}=0) years.

[1] Conner J K, Hartl D L (2004) A primer of ecological genetics. Sinauer Associates. 304 p
[2] Schmidt JJ, Pedersen JF, Bernards ML, Lindquist JL (2013) Rate of shattercane × sorghum hybridization in situ. Crop Sci 53:1677-1685

Management Strategies Evaluated:

- ✓ Six rotation strategies common to Nebraska and Kansas sorghum production areas were considered in the deterministic model (Figure 3).
- ✓ Given the variability in weed response to herbicide application from year to year, we also ran 500 simulations with stochastic levels of herbicide efficacy for each management strategy (Figure 4).

Model Parameters

Table 1. Life-history parameters of shattercane.

Parameter description	Base value[a]
Newly produced (fresh) seeds that are viable[3]	0.91
Fresh seeds that are predated[4]	0.70[b]
Viable seeds that survive in the seed bank over the winter[5,6]	0.15
Viable seeds that germinate[6]	0.35
Viable seeds that survive in the seed bank during the season[5]	0.30
Theoretical maximum seed production (S_{max}, seeds m^{-2})[7]	80510
Weed competitiveness (k_w)[7]	0.1277
Plant fecundity (p_{fec}, seeds plant^{-1})[8]	$p_{fec} = \frac{s_{\max} k_w d_w}{d_w\left(1+k_w d_w + k_c d_c\right)}$

[a] unless specified, values are reported as proportions; [b] adapted from johnsongrass (*Sorghum halepense* L.); [c] d_w is weed density (plants m^{-2}).

Figure 2. Sorghum field infested with shattercane.

Table 2. Crop and weed genotype-related parameters.

Parameter description	Inzen	Sorghum	Soybeans	Fallow/Wheat
RR and RS plants controlled during the season (%)*	60	60	99	99
SS plants controlled during the season (%)	99	60	99	99
Crop competitiveness x Density of the crop ($k_c d_c$)[7]	3.1052	3.1052	3.1052	0

*RR, RS, and SS represent homozygous resistant, heterozygous resistant, and homozygous susceptible plants to ALS-herbicide, respectively. Genotypes are assumed to be equally fit.

[3] Burnside OC (1965) Seed and phonological studies with shattercane Lincoln, NE: University of Nebraska Agricultural Experiment Station Bull. 220. 36.
[4] Bagavathiannan M, Norsworthy JK (2013) Postdispersal loss of important arable weed seeds in the midsouthern United States. Weed Sci 61:570-579
[5] Teo-Sherrel CPA, Mortensen DA (2000) Fates of buried *Sorghum bicolor* ssp. *drummondii* seed. Weed Sci 48:540-554
[6] Teo-Sherrell CPA, Mortensen DA, Keaton ME (1996) Fates of weed seeds in soil: a seeded core method of study. J Appl Ecol 33:1107-1113
[7] Werle, R (unpublished results)
[8] Renton M, Diggle A, Manalil S, Powles S (2011) Does cutting herbicide rates threaten the sustainability of weed management in cropping systems? J Theor Biol 283:14-27

Simulation Results

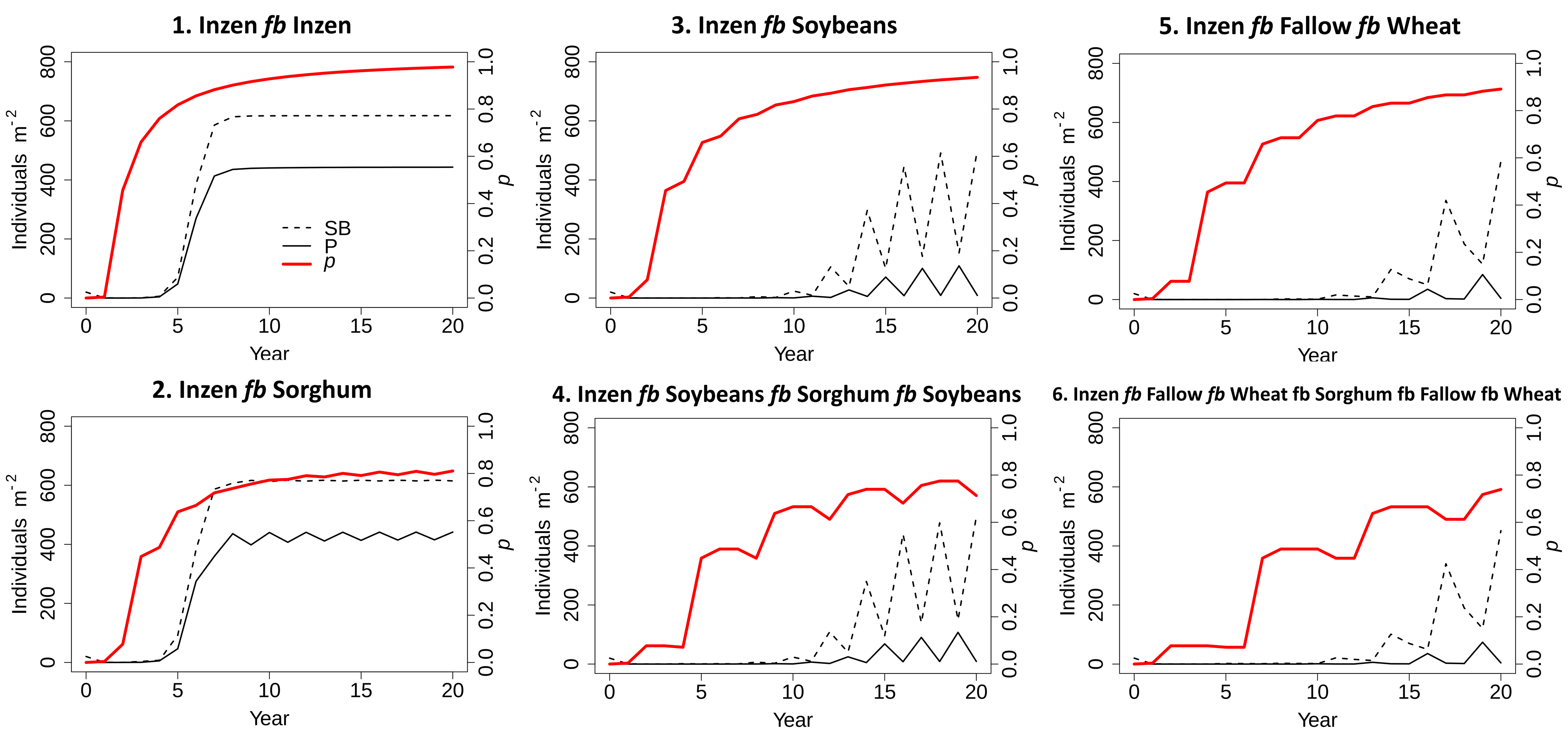

Figure 3: Number of seeds in the seed bank (SB), established plants (P), and frequency of the resistant allele (p) amongst P at census (dashed line in Fig 1) over time given different management strategies. Post-emergence ALS-herbicide (nicosulfuron) is only assumed to be used during ALS-sorghum years and effective alternative herbicides (e.g., glyphosate, clethodim) on soybeans, fallow and wheat years. Initial conditions: $SB_{t=0}$ = 20 seeds m^{-2}, $p_{t=0}$ = 0.0001.

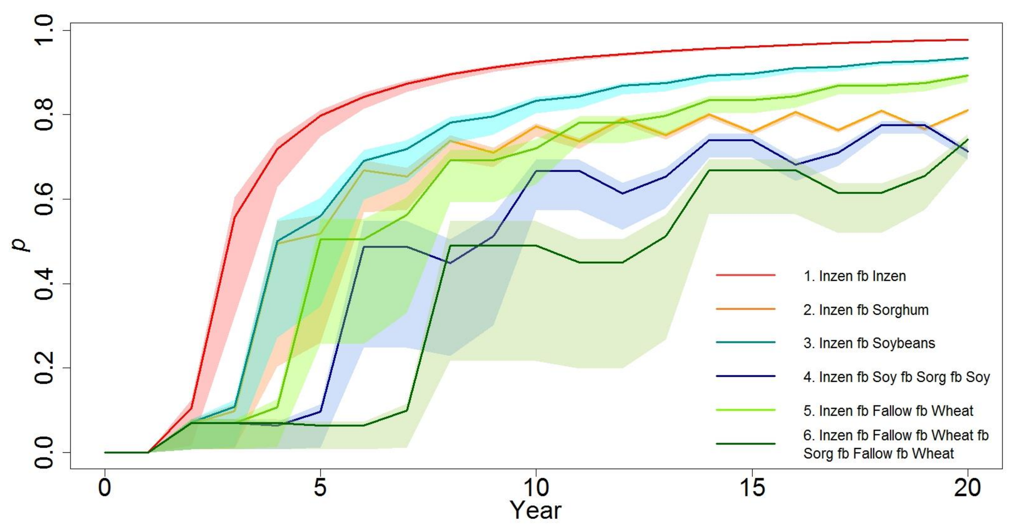

Figure 4. Frequency of the resistant allele (p) amongst established plants at census over time given different management strategies. Solid lines represent the median output of the stochastic model (500 runs; shaded areas represent the 95% confidence interval).

- Evolution of resistance was predicted to occur in a similar fashion in the deterministic (Figure 3) and stochastic (Figure 4) versions of the model.
- Evolution of resistance was predicted to occur rapidly if Inzen sorghum is planted continuously because of high selection pressure (ALS-herbicide application) and crop to weed gene flow.
- The time for resistance evolution was predicted to decrease with increased cropping system complexity (more crop diversity than continuous production of Inzen sorghum).
- Including conventional sorghum in the rotation helped to lower the frequency of the resistant allele in shattercane populations in subsequent generations.

Conclusions

- Crop and herbicide rotation will be key strategies to postpone the evolution of ALS-resistance and keep shattercane density at low levels in Inzen sorghum cropping systems.

Acknowledgements: **This research is being funded by the Sorghum Checkoff and DuPont.**