In the high control efficacy, as reflected by the 2019 reproductive potential, waterhemp population densities were projected to decrease or slightly increase (Figure 1 and Table 1).

Waterhemp seedbank densities were projected to decrease in the 3-year rotation regardless of corn weed management program ( and and in the 2-year and 4-year rotations where conventional weed management was applied on the corn phase ( and (Table 1). Waterhemp seedbank densities were projected to increase in the 2-year and 4-year rotation where low herbicide weed management was applied in corn ( and ) (Table 1).

In the 2-year rotation under low herbicide weed management, a 3.6-fold increase of seedbank size in the corn phase did not resulted in substantial annualized seedbank density increase () because the seedbank declined in half in the soybean phase (). In the 4-year rotation under low herbicide weed management, even though waterhemp seedbank densities substantially increased in the corn phase (), the annualized population could be stabilized (annualized ) because the population declined in the soybean () and alfalfa () phases.

All the relative ranking of elasticity of to the lower-level demographic parameters was consistent between corn weed management regimes (Figures 2 and ??). However, the overall population change rate can be reflected by the relative importance of each element on the elasticity of .

## Elasticities of population growth rates to lower-level demographic parameters

Even though all the matrices, but , were identical across scenarios, the ranking of each element contribution to the elasticity of might be slightly different across scenarios. For example, the the -decreasing case, the relative ranks of (the probability that a seed in the 2-20 cm stratum stay at that stratum) was higher that those of other , whereas in the population-growing case was the lowest among all . Similarly, was more important than in the elasticity of in the population-shrinking versus population-growing case. Consistent patterns in the importance of to elasticity of was observed in the two scenarios.

Because seed emergence and seedling survival rate contributed minimally to the elasticity of , this pattern suggests that even if weed control programs are of high, or even total efficacy, very few surviving plants prolifically producing new seeds, can sustain the population. The low relative importance of and can be attributed to the low emergence rate in weeds, the high weed control efficacy, while the high relative importance of of to elasticity of can be explained by the high individual fecundity.

In both scenarios, the patterns of contribution to elasticity of in the 3-year rotation was slightly different from the 2-year and 4-year rotations. The contribution of plant survival rate to elasticity of was non-existent in C2, S2, C4, S4, and O4 (absolute zeroes) but minimal in C3, S3, and O4 (very small positive values). The difference in contribution of plant survival rate on O3 and O4 might be attributed to the different companion crops to oat (red clover in O3 and alfalfa in O4).

The ranking of parameters or individual parameters to the elasticity of differed by rotation and crop phase (Figure 2). The seed preserving parameters were ranked higher in the corn phase of the 3-year rotation (C3) under both weed management regimes, the soybean phase of the 3-year rotation (S3) that followed corn under low herbicide weed management, the oat phases of the 3-year and 4-year rotations (O3 and O4) regardless of the preceding corn phase’s weed management regime, and the alfalfa phase of the 4-year rotation (A4) regardless of the preceding corn phase’s weed management regime. The seed producing parameters were ranked higher in the other crop environments (crop species in each rotation).

The elasticity of to fecundity rate, as a group, were ranked first in the corn phase of the 2-year rotation (C2) (43.13 and 3.15), the soybean phase of the 2-year rotation (S2) (0.75 and 4.18), the soybean phase of the 3-year rotation (S3) that followed corn under low herbicide weed management program (0.91), the corn phase of the 4-year rotation (C4) (305.24 and 323.07), and the alfalfa in the 4-year rotation (A4) (36.78 and 14.49) under both weed management regimes. The rate of pre-planting tillage induced seed movement to the 2-20 cm soil stratum was the first-ranked individual parameter to the elasticity of ’s in the corn phase of the 3-year rotation (C3) (1.1 and 1.1), the soybean in the 3-year rotation that followed corn under low herbicide weed management (0.89), the oat phase of the 3-year rotation (O3) (0.87 and 0.88), and the oat phase of the 4-year rotation (5.49 and 3.98). The overwinter survival rate of the seeds in the 0-2 cm soil stratum was the first-ranked individual parameter to the elasticity of ’s in the soybean phase of the 4-year rotation (S4) (3.32 and 2.41).

As s declined in this scenario, with some opportunity of increasing in the C4 phase, focusing on reducing plant fecundity in C4 would sufficiently stabilize , provided that the weed control efficacy in the subsequent three crop phases remained adequate.

Table 1: Population growth rate under high control efficacy condition.

|  |  | lambda | | phase wise lambda in | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Rotation | Corn weed management | annualized | rotation wise | corn | soybean | oat | alfalfa |
| 2-year | conventional | 0.62 | 0.38 | 0.85 | 0.50 |  |  |
| 2-year | low | 1.18 | 1.40 | 3.62 | 0.51 |  |  |
| 3-year | conventional | 0.58 | 0.20 | 0.56 | 0.51 | 0.65 |  |
| 3-year | low | 0.77 | 0.45 | 1.48 | 0.50 | 0.82 |  |
| 4-year | conventional | 0.64 | 0.17 | 0.62 | 0.56 | 1.57 | 0.53 |
| 4-year | low | 1.08 | 1.35 | 9.80 | 0.55 | 1.68 | 0.53 |

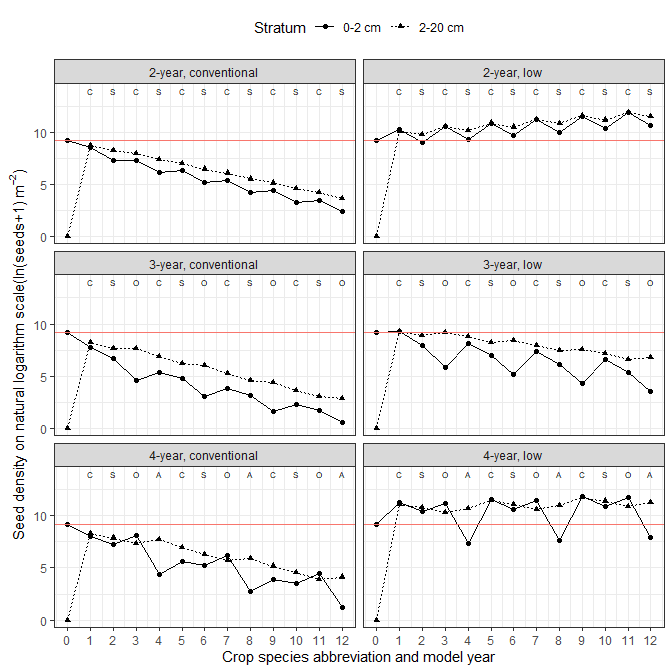


Figure 1: Scenario 1: Changes of seed densities in two soil strata after 12 model years in three rotations (2-year, 3-year, and 4-year) crossed with two corn weed management programs (conventional and low herbicide). The model started at year 0 with 10000 and 0 seeds per squared meter in the top (0 - 2 cm) and bottom (2 - 20 cm) strata, respectively. The red horizontal line shows the number of seeds in the top stratum at the beginning of the model clock. The annualized population growth rates are followed by their variances in brackets. The model years’ are labelled with the main crop species names’ abbreviations: C - corn, S - soybean, O - oat, and A - alfalfa.

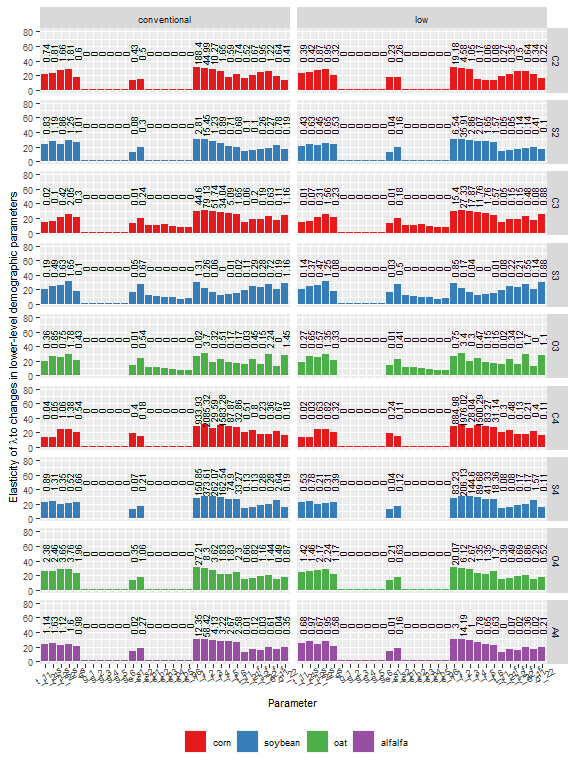


Figure 2: Scenario 1: Elasticity of annualized population growth rates to changes in lower-level demographic parameters. Bar height represents parameter’s ranking. Each bar is labeled with the absolute value of the contribution of the parameter to elasticity of annualized population growth rates (zeros from s\_s1 through s\_p6 in C3, S3, and O3 were due to rounding). Crop identities are color-coded by crop species. From left to right of the x-axis, the sub-annual demographic parameters are: t\_11\_s - probability that a seed in the 0 - 2 cm soil stratum stay at that statum after pre-planting tillage; t\_21\_s - probability that a seed in the 2 - 20 cm soil stratum move to the 0 - 2 cm soil stratum after pre-planting tillage; t\_12\_s - probability that a seed in the 0 - 2 cm soil stratum move to the 2 - 20 cm stratum after pre-planting tillage; and t\_22\_s - probability that a seed in the 2 - 20 cm soil stratum stay at that statum after pre-planting tillage; d - the probability that a seed is not germinating; g\_1 through g\_6: the probabiblites that a seed emerge to seedling cohorts 1 through 6; s\_s1 and s\_s2 - the survival rate of seeds in the 0 - 2 cm and 2 - 20 cm soil strata in the cropped season; s\_p1 through s\_p6: the probability that seedling cohorts 1 through 6 reach reproductive maturity; f\_1 through f\_6 - the fecundity rates of mature plant cohorts 1 through 6; t\_11\_f - probability that a seed in the 0 - 2 cm soil stratum stay at that statum after post-harvest tillage; t\_21\_f - probability that a seed in the 2 - 20 cm soil stratum move to the 0 - 2 cm soil stratum after post-harvest tillage; t\_12\_f - probability that a seed in the 0 - 2 cm soil stratum move to the 2 - 20 cm stratum after post-harvest tillage; and t\_22\_f - probability that a seed in the 2 - 20 cm soil stratum stay at that statum after post-harvest tillage; o\_11 and o\_12 - overwiter survival rates in the 0 - 2 cm and 2 - 20 cm soil strata.