**Reduce Herbicide Use While Maintaining Crop Yield: Insights from a Crop Rotation Experiment**

Weed communities in three cropping systems suitable for the Midwestern USA were studied from 2017 through 2020 to examine how crop diversification and the intensity of herbicide use affected weed stand density, and aboveground mass. A baseline 2-year cropping system with corn and soybean grown in alternate years was diversified with cool-season crops, namely oat and red clover, in 3-year and oat and alfalfa 4-year systems. Herbicides were not used in the cool-season crops. This study was pursued to address the current gaps of information concerning how the density and biomass of weeds respond to different crop environments and weed management programs (Fried et al., 2012; Ryan et al., 2010).

Integrating chemical and cultural weed management tools resulted in an overall reduction in the amount of herbicide applied (Table 1). In all the studied rotations, the corn phases under a low herbicide regime received banded herbicide application and interrow cultivation; the soybean phases received broadcast herbicide, and the oat and alfalfa phases (3-year and 4-year rotations) did not receive herbicide or cultivation. The reduction in herbicide use was associated with increases in weed density and aboveground mass. In the cool-season crop phases (oat intercropped with red clover, and oat intercropped with alfalfa) of the 3-year and 4-year rotations, the density of emerged weeds increased, but weed biomass did not increase, as compared with the warm-season crops (corn and soybean). Though there were more weeds (Table 2) in the lower-herbicide regime (banded herbicide and interrow cultivation) (Table 1), yields in the 3-year and 4-year rotations were as high or higher than in the conventionally managed 2-year rotation (Table 4).

Table 1: Weed management program from 2017 through 2020 field seasons. The baseline was established at 2-year rotation of corn and soybean under conventional herbicide weed management. In the 2-year rotation under low herbicide weed management regime, corn received banded herbicide on top of crop rows and interrow cultivation, but soybean received broadcast herbicide. The same conventional versus low herbicide designation applied on all the corn and soybean phases of the 3-year and 4-year rotations. Oat, red clover, and alfalfa received no herbicide, regardless of the herbicide regime applied on corn and soybean.

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| --- | --- | --- | --- | --- |
| Year |  | Broadcast herbicide | Banded herbicide and  interrow cultivation | Broadcast herbicide |
|  |  | Corn | | Soybean |
| 2017 | Hybrid or variety | Epley E1420 | Epley E1420 | Latham L2758 R2 |
| Herbicides applied (oz/ac) | PRE: thiencarbazone methyl (0.5), isoxaflutole (1.3) | POST: tembotrione (0.7) | PRE: flumioxazin (1.6);  POST: glyphosate as potassium salt (17.9), acifluorfen (3.2) |
| 2018 | Hybrid or variety | Epley E1730 | Epley E1730 | Latham L2758 R2 |
| Herbicides applied (oz/ac) | PRE: thiencarbazone methyl (0.5), isoxaflutole (1.3);  POST: mesotrione (1.5), nicosulfuron (0.8) | POST: tembotrione (0.8) | PRE: flumioxazin (0.096);  POST: glyphosate as potassium salt (1.540), lactofen (0.140) |
| 2019 | Hybrid or variety | “ | “ | Latham 2684L (Liberty Link) |
| Herbicides applied (oz/ac) | “ | POST: tembotrione (0.7) | PRE: flumioxazin (1.4);  POST: glufosinate ammonium (8.5), clethodim (1.9) |
| 2020 | Hybrid or variety | “ | “ | “ |
| Herbicides applied (oz/ac) | “ | “ | “ |

 “: identical to previous year

Table 2: Reduction in the amount of herbicide active ingredients applied in more diverse cropping systems as compared to a conventional 2-year corn and soybean system averaged from 2017 through 2020. The baseline was established at 2-year rotation of corn and soybean under conventional herbicide weed management. In the 2-year rotation under low herbicide weed management regime, corn received banded herbicide on top of crop rows and interrow cultivation, but soybean received broadcast herbicide. The same conventional versus low herbicide designation applied on all the corn and soybean phases of the 3-year and 4-year rotations. Oat, red clover, and alfalfa received no herbicide, regardless of the herbicide regime applied on corn and soybean. The minus sign in front of the percentages indicates the reduction in herbicide amount in the corresponding system as compared to the baseline.

|  |  |  |  |
| --- | --- | --- | --- |
|  | 2-year | 3-year | 4-year |
| Conventional: Broadcast herbicide | baseline | -33% | -50% |
| Low: Banded herbicide and interrow cultivation | -13% | -42% | -57% |

Table 3: Weed abundance in three cropping systems. The baseline was established at 2-year rotation of corn and soybean under conventional herbicide, i.e., broadcast. In the 2-year rotation under low herbicide regime, i.e., banded herbicide application and interrow cultivation, corn received banded herbicide on top of crop rows and interrow cultivation, but soybean received broadcast herbicide. The same conventional versus low herbicide regimes were consistent on all the corn and soybean phases of the 3-year and 4-year rotations. Oat, red clover, and alfalfa received no herbicide, regardless of the herbicide regime applied on corn and soybean. Zeroes were due to rounding. Means (± standard error, SE) were obtained from two linear models describing the effects of crop identity (species and rotation in which they occurred) and weed management regimes on weed density and biomass, respectively. The numbers in the table were converted from g/m2 and plants/m2 to oz/yd2 and plants/yd2.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Conventional:  Broadcast herbicide | | Low:  Banded herbicide and interrow cultivation | |
| Crop | Rotation | Density ± SE (plant/yd2) | Biomass ± SE  (oz/yd2) | Density ± SE (plant/yd2) | Biomass ± SE  (oz/yd2) |
| corn | 2-year | 6.4 (3.6) | 0.1 (0.1) | 6.3 (3.6) | 0.1 (0.1) |
| corn | 3-year | 2.5 (1.4) | 0.0 (0.0) | 5.1 (2.9) | 0.1 (0.1) |
| corn | 4-year | 6.7 (3.8) | 0.1 (0.1) | 5.4 (3.1) | 0.1 (0.1) |
| soybean | 2-year | 1.1 (0.6) | 0.1 (0.1) | 1.1 (0.7) | 0.1 (0.1) |
| soybean | 3-year | 0.6 (0.3) | 0.0 (0.0) | 0.4 (0.2) | 0.0 (0.0) |
| soybean | 4-year | 0.3 (0.2) | 0.0 (0.0) | 0.5 (0.3) | 0.0 (0.0) |
| oat/red clover | 3-year | 26.6 (15.0) | 0.5 (0.5) | 36.9 (20.8) | 0.5 (0.5) |
| oat/alfalfa | 4-year | 53.3 (30.0) | 1.5 (1.4) | 70.0 (39.3) | 1.6 (1.5) |
| alfalfa | 4-year | 57.5 (32.3) | 0.7 (0.6) | 51.8 (29.1) | 0.5 (0.5) |

Table 4: Mean crop yields in three cropping systems from 2017 to 2020. The baseline was established at 2-year rotation of corn and soybean under conventional herbicide, i.e., broadcast. In the 2-year rotation under low herbicide regime, i.e., banded herbicide application and interrow cultivation, corn received banded herbicide on top of crop rows and interrow cultivation, but soybean received broadcast herbicide. The same conventional versus low herbicide regimes were consistent on all the corn and soybean phases of the 3-year and 4-year rotations. Oat, red clover, and alfalfa received no herbicide, regardless of the herbicide regime applied on corn and soybean. Corn, soybean, and oat yields were in bushel/acre (bu/ac) and alfalfa yield was in ton/acre (ton/ac). Because county-specific alfalfa hay yields in 2019 and 2020 were unavailable at this writing, Boone County alfalfa yield was averaged over 2017 and 2018 and Iowa hay yield was averaged over all counties in 2017 and 2018 from all county-based values in 2017 and 2018 and two state-based values in 2019 and 2020.

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| --- | --- | --- | --- | --- | --- |
|  |  | Conventional:  Broadcast herbicide | Low:  Banded herbicide and  interrow cultivation | Iowa  (Boone)  yield | Unit |
| Crop | Rotation | Crop yield [95% confidence interval] | |  |  |
| corn | 2-year | 192.6 [182.9 , 202.9] | 196.0 [186.0 , 206.5] | 190.0 (185.0) | bu/ac |
| corn | 3-year | 208.6 [198 , 219.7] | 205.8 [195.3 , 216.8] |
| corn | 4-year | 208.1 [197.5 , 219.2] | 210.3 [199.6 , 221.5] |
| soybean1 | 2-year | 50.7 [35.6 , 72] | 50.8 [35.7 , 72.2] | 55.0 (53.8) |
| soybean1 | 3-year | 52.7 [37.1 , 74.9] | 53.1 [37.3 , 75.4] |
| soybean1 | 4-year | 59.6 [42.0 , 84.8] | 58.1 [40.9 , 82.5] |
| oat/red clover2,3 | 3-year | 61.4 [25.0 , 150.7] | | 71.6 (91.6) |  |
| oat/alfalfa2,3 | 4-year | 67.2 [27.4 , 165.0] | |
| alfalfa3 | 4-year | 3.6 [2.2 , 5.9] | | 3.6 (3.4) | ton/ac |

1: Soybean received broadcast herbicide, regardless of its preceding corn’s herbicide regime and its grain was harvested by herbicide regime applied to its preceding corn.

2: Red clover intercropped with oat and alfalfa intercropped with oat were not harvested.

3: Oat and alfalfa did not receive herbicide and their grain (oat) and hay (alfalfa) were pooled at harvest, over two weed management regimes applied to their preceding corn phases.

Among the most abundant weed species (giant and yellow foxtail pooled together) (Table 5), foxtail dominated in corn at oat, common waterhemp dominated in soybean, common lambsquarter dominated in oat, and dandelion dominated in alfalfa. This observation suggested alfalfa crop environment’s potentials to shift community composition to less challenging weed species. Knowing the challenging weed species in the field and documenting the weed pressure in response to a weed management program would be useful to adjust management strategies to avoid outbreaks. As weed seedbank density could be used as a sustainability indicator (Storkey and Neve, 2018; Liebman et al., 2021), having a record of weed seedbank composition over years could provide additional information for making long-term decisions about effective and sustainable weed management (Davis et al., 2005; Forcella et al., 1992; Forcella, 2003; Menalled et al., 2001).

Table 5: Relative abundance (%) of the most abundant weed species at the experiment site from 2017 through 2020. The means and standard deviations were aggregated from four blocks per year over four years. The baseline was established at 2-year rotation of corn and soybean under conventional herbicide, i.e., broadcast. In the 2-year rotation under low herbicide regime, i.e., banded herbicide application and interrow cultivation, corn received banded herbicide on top of crop rows and interrow cultivation, but soybean received broadcast herbicide. The same conventional versus low herbicide regimes were consistent on all the corn and soybean phases of the 3-year and 4-year rotations. Oat, red clover, and alfalfa received no herbicide, regardless of the herbicide regime applied on corn and soybean.

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Crop | Rotation | Common waterhemp | Common lambsquarter | Large crabgrass | Barnyardgrass | Foxtail | Dandelion |
|  |  | Conventional: Broadcast herbicide  relative abundance (%) followed by standard deviation in parentheses | | | | | |
| corn | 2-year | 25.1 (27.4) | 3.3 (9.0) | 9.1 (21.6) | 0.5 (1.8) | 59.7 (34.8) | 0.1 (0.2) |
| corn | 3-year | 23.1 (26.5) | 0.5 (2.1) | 11.9 (16.7) | 0.0 (0.0) | 53.7 (33.6) | 0.9 (3.1) |
| corn | 4-year | 14.7 (25.6) | 0.3 (1.0) | 9.9 (20.5) | 0.6 (1.8) | 58.6 (34.3) | 0.2 (0.8) |
| soybean1 | 2-year | 57.5 (41.2) | 19.0 (34.8) | 6.2 (19.7) | 0.0 (0.1) | 9.8 (15.3) | 0.0 (0.0) |
| soybean1 | 3-year | 52.1 (36.9) | 7.3 (11.7) | 1.9 (4.8) | 0.4 (1.3) | 32.2 (40.7) | 0.0 (0.0) |
| soybean1 | 4-year | 28.4 (38.0) | 21.2 (40.8) | 3.2 (9.5) | 0.9 (3.0) | 15.9 (30.5) | 6.7 (25.8) |
| oat/red clover2,3 | 3-year | 25.4 (24.4) | 38.6 (29.5) | 5.7 (19.0) | 3.0 (8.6) | 16.9 (15.0) | 3.6 (5.3) |
| oat/alfalfa2,3 | 4-year | 25.2 (21.2) | 21.6 (19.8) | 3.6 (5.3) | 3.2 (4.8) | 36.1 (20.1) | 5.2 (5.7) |
| alfalfa3 | 4-year | 2.3 (3.4) | 5.8 (14.9) | 21.6 (19.7) | 7.9 (15.7) | 18.3 (24.4) | 39.4 (33.2) |
|  |  | Low: Banded herbicide and interrow cultivation  relative abundance (%) followed by standard deviation in parentheses | | | | | |
| corn | 2-year | 20.7 (33.2) | 1.2 (2.7) | 0.3 (0.8) | 0.0 (0.0) | 64.8 (38.7) | 0.1 (0.3) |
| corn | 3-year | 8.5 (15.3) | 5.2 (8.1) | 0.2 (0.9) | 0.0 (0.0) | 75.8 (20.9) | 0.2 (0.6) |
| corn | 4-year | 12.8 (18.4) | 3.3 (12.0) | 2.8 (6.0) | 0.0 (0.0) | 59.8 (31.7) | 1.2 (3.8) |
| soybean1 | 2-year | 54.6 (39.2) | 16.6 (32.3) | 0.3 (0.7) | 0.2 (0.6) | 23.6 (28.7) | 0.0 (0.0) |
| soybean1 | 3-year | 39.4 (39.7) | 18.8 (31.6) | 1.6 (5.4) | 1.9 (6.6) | 28.0 (35.2) | 0.0 (0.0) |
| soybean1 | 4-year | 28.1 (37.7) | 8.4 (24.7) | 4.8 (16.5) | 0.0 (0.0) | 24.5 (30.9) | 2.8 (9.4) |
| oat/red clover2,3 | 3-year | 18.2 (22.7) | 31.2 (29.4) | 2.1 (7.7) | 0.3 (0.8) | 38.9 (30.3) | 3.9 (11.3) |
| oat/alfalfa2,3 | 4-year | 24.0 (22.4) | 21.0 (13.5) | 4.7 (9.4) | 1.5 (3.4) | 38.9 (21.2) | 5.1 (6.2) |
| alfalfa3 | 4-year | 8.2 (17.9) | 3.4 (5.9) | 22.4 (25.8) | 2.7 (6.7) | 20.3 (24.7) | 39.2 (35.6) |

1: Soybean received broadcast herbicide, regardless of its preceding corn’s herbicide regime and its grain was harvested by herbicide regime applied to its preceding corn.

2: Red clover intercropped with oat and alfalfa intercropped with oat were not harvested.

3: Oat and alfalfa did not receive herbicide and their grain (oat) and hay (alfalfa) were pooled at harvest, over two weed management regimes applied to their preceding corn phases.

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The code for data analysis can be found at: <https://doi.org/10.5281/zenodo.5980943>

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