Supplementary Table 1. Fertility effects on crop-weed competition and crop yield

Crop species	Weed species[a]	Treatment[b]	Effect of nutrients on competition[c]	Does weed biomass or crop biomass and/or yield increase faster with nutrients?[c]	Effect of nutrients on crop yield[c]	Citation
Brassica napus, Hordeum vulgare	*Avena fatua*	Four-year field study with *A. fatua* sown. Added N, P, K, S at recommended or reduced (50% or 0%) rates	In *B. napus* plots (with herbicides), reducing fertility increased weed biomass and reduced crop yield. In *H. vulgare* plots, reducing fertility did not affect either variable.	Crop yield (*B. napus* only)	Increased (*B. napus*); no change (*H. vulgare*)	(Harker et al. 2013)
Brassica napus	*Sinapis arvensis*	Two-year field study with *S. arvensis* sown (up to 40 plants m^{-2}). Added N (up to 200 kg ha^{-1})	At high *S. arvensis* densities, grain yield peaked at moderate N and decreased at high N.	Weed biomass	Increased at low N, then decreased at high N	(Naderi and Ghadiri 2011)
Glycine max	*Amaranthus tuberculatus*	Two-year field study with *A. tuberculatus* sown. Added composted swine manure (up to 8,000 kg C ha^{-1}) with synthetic N (higher rates in no-compost treatments)	Compost increased *A. tuberculatus* biomass but not *G. max* yield. Under strong competition (weed sown at planting), compost reduced yield.	Weed biomass	Decreased	(Menalled et al. 2004)
Hordeum vulgare	*Capsella bursa-pastoris, Chenopodium album, Papaver rhoeas, Sinapis arvensis, Spergula arvensis, Viola arvensis*	Greenhouse, replacement design. Added N (up to 150 kg ha^{-1}) or P up to 60 kg ha^{-1})	Weeds grown alone (except *Spergula arvensis*) increased dry weight less than barley grown alone. Weeds did not grow well in competition with barley, but some were luxury consumers of N and P.	Crop biomass (except *Spergula arvensis*).	Grain yield not reported. Increase probable.	(Andreasen et al. 2006)
Hordeum vulgare	*Lolium rigidum*	Greenhouse, replacement design. Added N [up to 1792 mg CAN (33.5% N) per 8 kg soil]	Nitrogen did not affect the competitive relationship between barley and ryegrass.	Similar rates	Increased	(González-Ponce 1998)
Hordeum vulgare, Triticum aestivum	In *H. vulgare*: *Chenopodium album, Urtica urens, Lamium spp.* In *T. aestivum*: *Stellaria media, Lamium spp., Veronica spp.*	One-year field study, only crops sown. Added N (up to 90 kg ha^{-1} in *H. vulgare* or 162 kg ha^{-1} in *T. aestivum*)	*C. album* and *Lamium* spp. had lower N optima than *H. vulgare* while *U. urens* had a higher nitrogen optimum. All *T. aestivum* weeds had lower nitrogen optima than the crop.	Crop biomass (except *U. urens*)	Grain yield not reported. Increase probable	(Jørnsgård et al. 1996)

Hordeum vulgare and *Pisum sativum* (intercrop)	*Sinapis alba*	Two-year field study. *S. alba* sown with *H. vulgare* and small or large *P. sativum* varieties. Added N (180 kg ha^{-1}).	N increased mustard biomass more than the yield of either crop. Small *P. sativum* cultivar was overtopped by *S. alba* at high N.	Weed biomass	Increased (*H. vulgare*, large *P. sativum* variety) or decreased (small variety).	(Liebman 1989)
Lactuca sativa	*Amaranthus hybridus*, *Portulaca oleracea*	Greenhouse study. In each pot, one crop and one weed plant were grown together with aboveground space restricted. Added P (up to 0.8 g L^{-1} soil)	Increasing P increased biomass for *L. sativa* and *P. oleracea* but not *A. hybridus* (luxury consumption). *A. hybridus* competed primarily through light interception; *P. oleracea* was a stronger competitor for P.	Crop biomass/yield	Increased (shoot biomass)	(Santos et al. 2004)
Oryza sativa	*Amaranthus spinosus*, *Cyperus rotundus*, *Eleusine indica*, *Rottboellia cochinchinensis*	Greenhouse experiments with two-species and five-species mixtures. Added N (up to 103 mg kg^{-1} soil)	In two-species mixtures, competitive ability of the crop relative to weeds increased (*C. rotundus*), decreased (*E. indica*), or was unchanged (others) with increasing N.	Crop biomass (in five-species mixture, crop's proportion of total biomass increased faster than all species except *A. spinosus*)	Grain yield not reported. Increase probable	(Ampong-Nyarko and de Datta 1993)
Oryza sativa	*Ischaemum rugosum*	Greenhouse experiment with multiple crop seedlings and one weed seedling per pot. Added N (up to 150 kg ha^{-1})	Increasing N increased crop biomass faster than weed biomass. High N also reduced the height advantage of the weed.	Crop biomass	Grain yield not reported. Increase probable	(Awan et al. 2014)
Oryza sativa	*Rottboellia cochinchinensis*	Greenhouse experiment with higher crop densities. Added N (up to 150 kg ha^{-1})	Increasing N increased weed biomass faster than crop biomass (also increased). High N increased the height advantage of the weed.	Weed biomass	Grain yield not reported. Increase probable	(Awan et al. 2015)
Oryza sativa	*Cyperus rotundus*	Two-year field experiment with *C. rotundus* sown. Added N (up to 120 kg ha^{-1})	*C. rotundus* biomass and *O. sativa* grain yield both increased with N. The relative decreases in grain yield between weed densities were higher at 60 kg ha^{-1} than in the unfertilized control.	Crop yield (percent increase between 0 and 60 kg ha^{-1}); weed biomass (60 to 120 kg ha^{-1})	Increased (no further change above 60 kg ha^{-1})	(Okafor and Datta 1976)
Phaseolus vulgaris	*Sinapis arvensis*	Three-year field experiment with *S. arvensis* sown. Added NH_4NO_3 (84 kg N ha^{-1})	N increased crop seed yield in 2/3 years in monoculture but only 1/3 years in competition with *S. arvensis*. N tended to increase weed biomass (n.s.)	Neither (crop and weed unaffected) or crop yield (1 year)	No change or increased	(Liebman and Gallandt 2002)

Phaseolus vulgaris	*Amaranthus retroflexus*	Two-year field experiment. Sowed erect and semi-erect *P. vulgaris* and *A. retroflexus*. Added N (up to 200 kg ha^{-1})	At high *A. retroflexus* density, crop biomass and yield decreased with N. The semi-erect cultivar was more competitive against the weed.	Weed biomass not reported but likely increased faster	Decreased	(Saberali et al. 2012)
Phaseolus vulgaris	*Echinochloa crus-galli*	Two-year field study with weed sown in grow-bags to prevent belowground competition. Added N (up to 280 kg ha^{-1})	Increasing N increased weed biomass, reducing the magnitude of the yield response to N. Crop biomass and yield plateaued at 140 kg ha^{-1} while weed biomass continued to increase.	Weed biomass	Increased	(Saberali and Mohammadi 2019)
Phaseolus vulgaris	*Bidens pilosa, Galinsoga parviflora, Solanum nigrum*	Field study with three site-seasons, weeds sown. Tested all 2 to 3-nutrient combinations of N (50 kg ha^{-1}), P (50 kg ha^{-1}), and K (60 kg ha^{-1})	Relative competitiveness of crop (based on dry weight) decreased with added N or P but increased with added K.	Weed biomass (N and P) or crop biomass (K).	Increased (K addition at Cornell); no change (prevailing pattern in Uganda)	(Ugen et al. 2002)
Raphanus sativus	*Cyperus rotundus*	Greenhouse study with added N (up to 330 kg ha^{-1}) and field study with weed sown, added N (up to 200 kg ha^{-1})	Under high *C. rotundus* densities, *R. sativus* yield decreased as N rate increased in the greenhouse (weed biomass increased, then decreased). N also exacerbated yield losses in the field.	Weed biomass	Decreased	(Santos et al. 1998)
Solanum tuberosum	*Chenopodium album, Setaria faberi, Solanum physalifolium*	Two-year field study with weeds sown. Added cured dairy compost (up to 8,000 kg C ha^{-1}), increasing P, K, Ca, Mg, and S over the control. N balanced with inorganic fertilizer.	Compost increased potato yield but did not affect biomass of any weed species	Crop biomass and yield	Increased	(Lindsey et al. 2013)
Triticum aestivum	*Lolium perenne* ssp. *multiflorum*	Two-year field study with two *T. aestivum* cultivars and weed sown. Added N (up to 168 kg of N ha^{-1})	At high weed densities, high N was associated with greater weed interference and failed to improve or reduced yields.	Weed biomass not reported but likely increased faster	Decreased or no change	(Appleby et al. 1976)
Triticum aestivum	*Amaranthus retroflexus, Avena fatua, Lolium persicum, Sinapis arvensis*	Greenhouse experiment, replacement design. Added N (up to 240 mg kg^{-1} soil)	*A. retroflexus* became a stronger competitor at high N (increased aggressivity index based on biomass); competitiveness of others did not respond to N rate.	Weed biomass (*A. retroflexus*); similar rates (others)	Grain yield not reported. Increase probable	(Blackshaw and Brandt 2008)

Triticum aestivum	*Avena fatua, Bassia scoparia, Lolium persicum, Malva pusilla*	Greenhouse experiment, replacement design. Added P (up to 45 mg kg^{-1} soil)	The biomass-based aggressivity of weeds increased (*M. pusilla*), decreased (*B. scoparia, L. persicum*), or remained the same (*A. fatua*) with increasing P.	Weed biomass (*M. pusilla*); crop biomass (*A. fatua*); similar rates (others)	Grain yield not reported. Increase probable	(Blackshaw and Brandt 2009)
Triticum aestivum	*Hordeum jubatum*	Five-year field study. Tested effects of N placement and rate (up to 120 kg ha^{-1}), tillage, and glyphosate timing.	*H. jubatum* was responsive to N and could limit increases in *T. aestivum* yield, especially if N was broadcast without effective weed control	Crop yield or weed biomass, depending on application method and weed control	Increased (most cases); no change (no-till in 1 year)	(Blackshaw et al. 2000)
Triticum aestivum	*Avena fatua*	Three-year field study with weed sown. Added N (up to 168 kg ha^{-1})	Decreasing yield with N at high *A. fatua* density was attributed to increasing competition. Wild oat panicle density increased with N	Weed biomass not reported but likely increased faster	Decreased	(Carlson and Hill 1986)
Triticum aestivum	*Lolium perenne* ssp. *multiflorum*	Greenhouse experiment, replacement design. Added P (0 or 68.4 kg ha^{-1})	*T. aestivum* grew more than the weed under low P in monoculture. In mixture, *T. aestivum* was more competitive at recommended P but more limited by low P, resulting in similar growth at low P.	Crop biomass	Grain yield not reported. Increase probable	(Cralle et al. 2003)
Triticum aestivum	*Chenopodium album, Phalaris minor, Sinapis arvensis*	Greenhouse experiment, replacement design. Added N (20 or 120 kg ha^{-1})	Weeds were more competitive (biomass-based) than the crop at both N levels (*C. album*), low N (*P. minor*), or high N (*S. arvensis*)	Weed biomass (*S. arvensis*); crop biomass (*P. minor*); similar rates (*C. album*)	Increased	(Iqbal and Wright 1997)
Triticum aestivum	*Calystegia hederacea*	Two-year field study. Added N (“farmer’s practice” of 276 kg N ha^{-1} over 3 applications or an N_{min}-based rate of 138 to 306 kg N ha^{-1})	Farmer’s practice decreased weed biomass relative to control and N_{min} but maximized *T. aestivum* biomass and yield.	Crop biomass and yield	Increased	(Menegat et al. 2013)
Zea mays	*Digitaria sanguinalis, Echinochloa crus-galli, Portulaca oleracea, Sida spinosa*	Two-year field study. Tested effects of N (300 to 375 kg N ha^{-1}) and weed control methods.	Only *P. oleracea* and *Z. mays* increased biomass with N. Adding more N favored growth and yield of *Z. mays* more than weeds.	Crop biomass and yield (or biomass of well-controlled *P. oleracea*)	Increased	(Abouziena et al. 2007)

Zea mays	*Abutilon theophrasti*	Two-year field study with weeds sown. Added N (up to 240 kg N ha^{-1})	N-induced increase in biomass was greater for *A. theophrasti* than *Z. mays*, but the effect of N on yield loss due to *A. theophrasti* was not consistent across site-years	Weed biomass	Increased	(Barker et al. 2006)
Zea mays	*Setaria viridis*	Three-year field study with weeds sown. Added N (up to 200 kg ha^{-1})	Yield increased with N, which had a greater influence than weed density. Percent losses in grain yield due to *S. viridis* were higher at low N.	Only crop yield reported; weed biomass may have increased slower or failed to increase	Increased	(Cathcart and Swanton 2003)
Zea mays	*Amaranthus palmeri*	Two-year field study with weeds sown, irrigated and non-irrigated environments. Added N (up to 224 kg ha^{-1})	Percent yield loss at a given weed density was usually similar across N rates but reduced at high N in one environment-year. Crop yield increased with N mostly in irrigated treatments.	Rates were likely similar in three environment-years (crop may have increased faster in the fourth)	Increased in irrigated environments, little effect in dryland	(Ruf-Pachta et al. 2013)
Zea mays	*Abutilon theophrasti*	Greenhouse study with compost-amended and unamended soils, with or without added N (up to 60 ppm N pot^{-1}). Two-year field study with weed sown, amended or unamended soils, and no additional N, reduced rate, or recommended rate	In the greenhouse, weed interference in crop biomass tended to decrease with increasing N in unamended soil and increase with N in compost-amended soil. In the field, weed interference in crop biomass tended to decrease with increasing N in both soil types. Weed interference in grain yield did not vary with N or soil type.	In the field, probably crop biomass or similar rates	Increased (2 of 3 site-years)	(Wortman et al. 2011)

[a] In field studies, this column refers to dominant species.

[b] We include papers involving interactions among 3+ species but exclude analyses in which weed species-specific responses to nutrients are not reported.

[c] Unless otherwise noted, these results refer to weedy treatments under high weed pressure if multiple densities or weed planting times were tested.

References

Abouziena HF, El-Karmany MF, Singh M, Sharma SD (2007) Effect of nitrogen rates and weed control treatments on maize yield and associated weeds in sandy soils. Weed Technol 21:1049–1053

Ampong-Nyarko K, de Datta SK (1993) Effects of nitrogen application on growth, nitrogen use efficiency and rice-weed interaction. Weed Res 33:269–276

Andreasen C, Litz A-S, Streibig J (2006) Growth response of six weed species and spring barley (*Hordeum vulgare*) to increasing levels of nitrogen and phosphorus. Weed Res 46:503–512

Appleby AP, Olson PD, Colbert DR (1976) Winter wheat yield reduction from interference by Italian ryegrass. Agron J 68:463–466

Awan TH, Chauhan BS, Cruz PCS (2014) Physiological and morphological responses of *Ischaemum rugosum* Salisb. (wrinkled grass) to different nitrogen rates and rice seeding rates. PLoS One 9:e98255

Awan TH, Sta Cruz PC, Chauhan BS (2015) Ecological significance of rice (*Oryza sativa*) planting density and nitrogen rates in managing the growth and competitive ability of itchgrass (*Rottboellia cochinchinensis*) in direct-seeded rice systems. J Pest Sci 88:427–438

Barker DC, Knezevic SZ, Martin AR, Walters DT, Lindquist JL (2006) Effect of nitrogen addition on the comparative productivity of corn and velvetleaf (*Abutilon theophrasti*). Weed Sci 54:354–363

Blackshaw RE, Brandt RN (2008) Nitrogen fertilizer rate effects on weed competitiveness is species dependent. Weed Sci 56:743–747

Blackshaw RE, Brandt RN (2009) Phosphorus fertilizer effects on the competition between wheat and several weed species. Weed Biol Manag 9:46–53

Blackshaw RE, Semach G, Li X, O'Donovan JT, Harker KN (2000) Tillage, fertiliser and glyphosate timing effects on foxtail barley (*Hordeum jubatum*) management in wheat. Can J Plant Sci 80:655–660

Carlson HL, Hill JE (1986) Wild oat (*Avena fatua*) competition with spring wheat: effects of nitrogen fertilization. Weed Sci 34:29–33

Cathcart RJ, Swanton CJ (2003) Nitrogen management will influence threshold values of green foxtail (*Setaria viridis*) in corn. Weed Sci 51:975–986

Cralle HT, Fojtasek TB, Carson KH, Chandler JM, Miller TD, Senseman SA, Bovey RW, Stone MJ (2003) Wheat and Italian ryegrass (*Lolium multiflorum*) competition as affected by phosphorus nutrition. Weed Sci 51:425–429

González-Ponce R (1998) Competition between barley and *Lolium rigidum* for nitrate. Weed Res 38:453–460

Harker KN, O'Donovan JT, Turkington TK, Blackshaw RE, Johnson EN, Brandt S, Kutcher HR, Clayton GW (2013) Weed interference impacts and yield recovery after four years of variable crop inputs in no-till barley and canola. Weed Technol 27:281–290

Iqbal J, Wright D (1997) Effects of nitrogen supply on competition between wheat and three annual weed species. Weed Res 37:391–400

Jørnsgård B, Rasmussen K, Hill J, Christiansen JL (1996) Influence of nitrogen on competition between cereals and their natural weed populations. Weed Res 36:461–470

Liebman M (1989) Effects of nitrogen fertilizer, irrigation, and crop genotype on canopy relations and yields of an intercrop/weed mixture. Field Crops Res 22:83–100

Liebman M, Gallandt ER (2002) Differential responses to red clover residue and ammonium nitrate by common bean and wild mustard. Weed Sci 50:521–529

Lindsey AJ, Renner KA, Everman WJ (2013) Cured dairy compost influence on weed competition and on ‘Snowden’ potato yield. Weed Technol 27:378–388

Menalled FD, Liebman M, Buhler DD (2004) Impact of composted swine manure and tillage on common waterhemp (*Amaranthus rudis*) competition with soybean. Weed Sci 52:605–613

Menegat A, Jäck O, Zhang J, Kleinknecht K, Müller BU, Piepho H-P, Ni H, Gerhards R (2013) Japanese bindweed (*Calystegia hederacea*) abundance and response to winter wheat seeding rate and nitrogen fertilization in the North China Plain. Weed Technol 27:768–777

Naderi R, Ghadiri H (2011) Competition of wild mustard (*Sinapis arvense* L.) densities with rapeseed (*Brassica napus* L.) under different levels of nitrogen fertilizer. J Agric Sci Technol 13:45–51

Okafor LI, Datta SKD (1976) Competition between upland rice and purple nutsedge for nitrogen, moisture, and light. Weed Sci 24:43–46

Ruf-Pachta EK, Rule DM, Dille JA (2013) Corn and palmer amaranth (*Amaranthus palmeri*) interactions with nitrogen in dryland and irrigated environments. Weed Sci 61:249–258

Saberali SF, Modarres-Sanavy SAM, Bannayan M, Baghestani MA, Rahimian Mashhadi H, Hoogenboom G (2012) Dry bean competitiveness with redroot pigweed as affected by growth habit and nitrogen rate. Field Crops Res 135:38–45

Saberali SF, Mohammadi K (2019) The above-ground competition between common bean (*Phaseolus vulgaris* L.) and barnyardgrass (*Echinochloa crus-galli* L.) affected by nitrogen application. Phytoparasitica 47:451–460

Santos BM, Dusky JA, Stall WM, Bewick TA, Shilling DG (2004) Mechanisms of interference of smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) on lettuce as influenced by phosphorus fertility. Weed Sci 52:78–82

Santos BM, Morales-Payan JP, Stall WM, Bewick TA (1998) Influence of purple nutsedge (*Cyperus rotundus*) density and nitrogen rate on radish (*Raphanus sativus*) yield. Weed Sci 46:661–664

Ugen MA, Wien HC, Wortmann CS (2002) Dry bean competitiveness with annual weeds as affected by soil nutrient availability. Weed Sci 50:530–535

Wortman SE, Davis AS, Schutte BJ, Lindquist JL (2011) Integrating management of soil nitrogen and weeds. Weed Sci 59:162–170