The hidden land use cost of widespread cover cropping

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Abstract

Cover cropping is a cornerstone of sustainable agriculture, however, little attention is paid to the cover crop production supply chain. Here we explore land use requirements to supply the United States maize production area with cover crop seed, identifying an average 5.4% of current production area being required, with the most popular species of hairy vetch requiring 11.9%. We then highlight avenues for avoiding this high land use cost.

Main Text

Cover crops are commonly included in strategies aimed at increasing the sustainability of agricultural production systems. Their environmental and societal benefits include improved soil retention [1], weed control [2], soil physical properties [3], carbon sequestration [4], biocontrol services [5], water quality [6], and nutrient cycling [7,8]. Universities, nonprofits, and industry are all now working to achieve wider adoption of cover crops through a mixture of research, advocacy, education, and outreach [9]. In part, these efforts have contributed to an increase of 2.0 million ha of cover crops planted in the U.S. from 2012 and 2017, with total cover crop hectarage reaching 6.2 million ha as of 2017 [10]. Yet, in spite of this uptick in adoption, just 1.7% of U.S. farmland currently incorporates a cover crop, meaning the strategy does not yet have widespread impact in commodity crop production systems [10]. Here, we step back from the field-scale benefits of cover cropping and consider what infrastructure would be needed to upscale cover cropping and what barriers remain to achieving this scale.

Perhaps the most foundational need for scaling cover crops is a robust seed industry that can provide an affordable and high quality input for farmers. Growing cover crops *for seed* in temperate agroecosystems usually requires foregoing production of traditional cash crops on the same land in the same year because current cover crop species require most of a temperate growing season to reach reproductive maturity. As a result, widespread cover crop adoption would likely require significant arable land allocation for seed production, potentially forcing the conversion of farmed lands from cash crops, pasture, and natural systems to cover crop seed production (Figure 1). The potential scope and implications of such land use changes have not been quantified.

Therefore, we ask: how much land would cover crop seed production require if cover cropping was adopted widely across a major cash crop production area, such as the 34 million ha devoted to U.S. maize production? To answer this question, we compiled the generally accepted seed yields and seeding rates for 17 different cover crops from state yield trials, published literature, commercial seed catalogs, and farmer bulletins (Table S1). These cover crops are marketed as suitable for use in the U.S. [11]. For each cover crop, minimum and maximum seed yield per hectare and seeding rate per hectare were used to bound the area that could be cultivated with the cover crop from a single hectare of seed production (Figure 1A), and the total number of hectares needed for seed production of the cover crop so as to plant the entire U.S. maize cropland (Figure 1B).

Assuming that the total maize hectarage does not change for any reason inherent to this transition, we find that the land requirements for production of cover crop seed would be on average 2,053,407 hectares, which is equivalent to 5.6% of the U.S. maize farmland. Rye (*Secale cereale* L.) – a midrange seed yielding cover crop, would require 1,660,000 hectares (4.5% of maize farmland), while hairy vetch (*Vicia villosa* ssp.) – the lowest seed yielding – would require as much as 4,410,000 hectares (11.9% of maize farmland).

For the sake of illustration, we introduce two hypothetical scenarios for land use conversion for cover crop seed production. In scenario one, we consider direct competition of land between maize production and cover crop seed production and assume no change in yield due to cover cropping. If based on 2017 average maize yield data we converted land used for maize production to cover crop seed production, rye seed production would result in 16,400,000 MT of maize grain removed from the market, while hairy vetch seed production would result in 44,100,000 MT of grain removed. This larger number is comparable to the annual amount of maize grain lost to disease in the U.S. in 2015, which amounts to 13.5% of total production [12].

To avoid the tradeoffs caused by producing cover crop seed on current cash crop lands, alternatives may be proposed. For example, we consider a second scenario for cover crop seed production focused on the marginal lands held in the conservation reserve program (CRP), which pays farmers to restore marginal and ecologically sensitive land to native habitat [13]. Cover cropping the entire U.S. maize area would require the equivalent of 18% (rye) to 49% (hairy vetch) of the 2019 CRP enrollment for cover crop seed production [14]. Using this much CRP land to produce cover crop seed would significantly disrupt the program's conservation and ecosystem services benefits.

Our simple calculations and benchmark scenarios are meant to bring attention to a major, but barely recognized challenge of scaling cover crops - the considerable amount of land required for seed production. The low and uncertain seed yield reported for most cover crops is a major driver of this potential impact. Addressing projected cover crop seed production needs may help pre-empt social conflicts over how to enhance agricultural sustainability [15], avoiding major disputes that have impacted other competing land use developments, for instance such as those observed in the food versus fuel debates [16].

Our seed yields are estimates based on compilations from multiple sources, as the United States Department of Agriculture does not keep statistics on cover crop seed yields, and agronomists researching these crops rarely report seed yields in the formal literature because the crops are most often terminated before maturity. Improved data would refine our land use estimates. Still, these data highlight that cover crops are “under developed” cultivated species in comparison to the generally much higher seed yields of cash crops of similar taxonomic backgrounds.

Our results suggest that cover crop breeding research should shift to emphasize increased seed yield. Only a handful of cover crops are actively being bred for seed productivity (i.e., Pennycress and Camelina; [17]). Most breeding has focused on ecosystem service values [9] and forage quality [11], with seed yields holding little to no priority. Fortunately, advanced breeding techniques and public-private partnerships make it possible to increase the tempo of plant breeding and the subsequent adoption by farmers [18]. In particular, breeding might focus on classic domestication syndrome traits such as non-shattering, lack of dormancy, and flowering time [19]. Most of these traits have a well-known genetic basis [20,21]. Leveraging these abilities to improve seed yields may reduce land use impacts, provide economic benefits to seed producers, and improve access to cover crop seed.

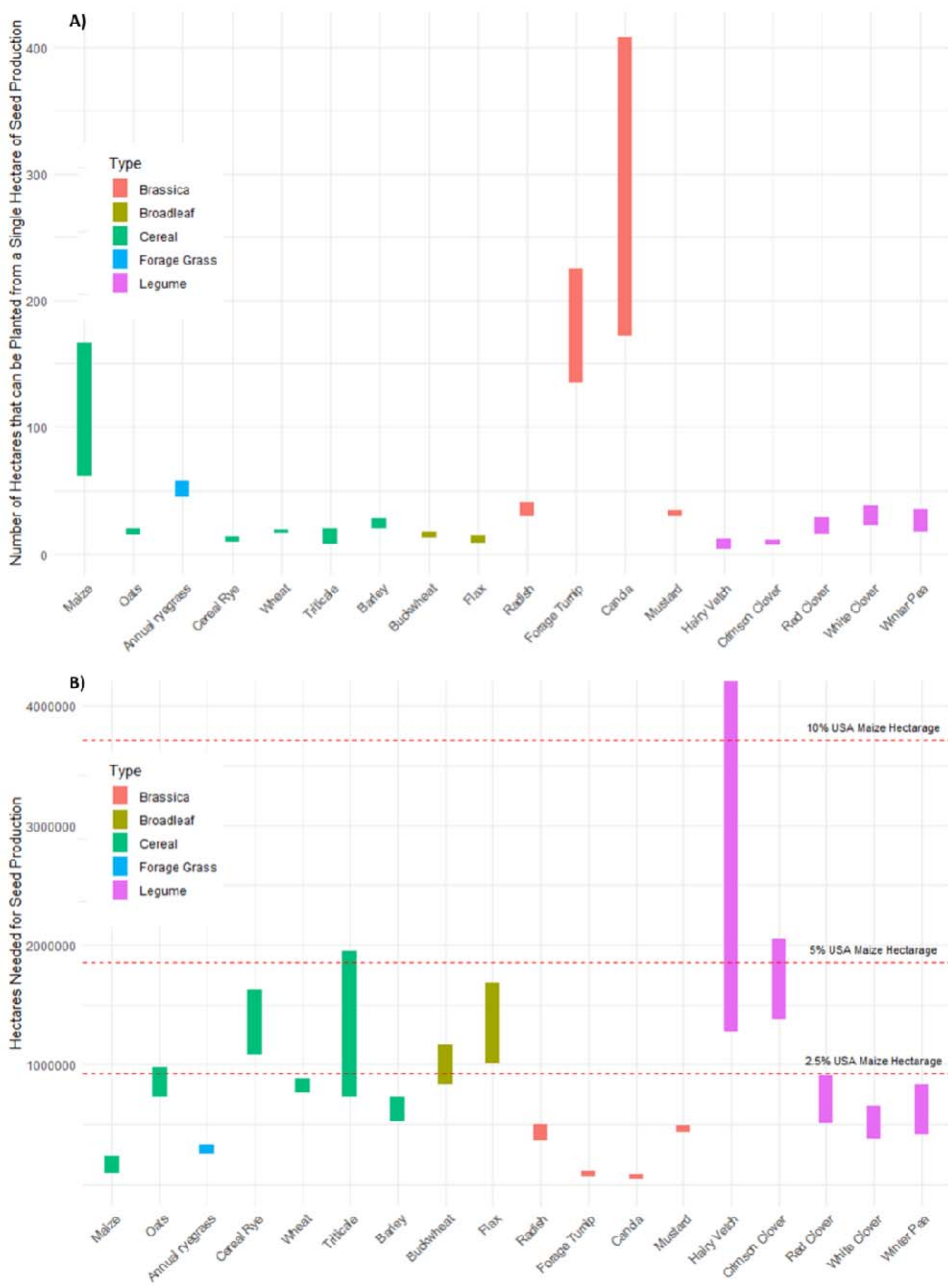
For cover crops to be widely planted, our analysis suggests that land use for cover crop seed production will have large and poorly understood economic, environmental, and food production impacts. Two research areas need immediate attention in order to move forward with planning for scaling cover crops: 1) to what extent does common agronomic knowledge actually represent the yields achieved by cover crop seed growers? And 2) if seed yields for cover crops are as low as found in our compilation of data sources, to what extent can we leverage breeding to increase seed yields while simultaneously improving the fertilizer and other ecosystem service benefits of cover crops? The answers may help indicate whether cover crops, an essential strategy for sustainable crop production, will be able to move from theory to practice.

Methods

Areal extent of seed production calculation

To identify the total number of hectares an individual hectare of seed production could crop we divided maximum yield and minimum yield by seeding rate. To calculate the number of hectares needed to produce cover crop seed for the entire U.S. maize hectarage, total U.S. hectares from the National Agricultural Statistics Service was multiplied by the seeding rate for each cover crop per hectare, then divided by minimum yield and maximum yield identified in the literature to identify the range of production extents needed to plant each individual cover. This seed production area was then divided by total cropped maize hectarage across the United States to identify the percent of hectarage of maize production that cover crop seed production would be equivalent to.

Figure 1. A) Range of seed production potential from a single hectare based on commonly reported cover crop yields and seeding rates in the published literature and USDA extension **B**) Range of area needed to support seed production based on commonly reported cover crop yields and seeding rates in the published literature and USDA extension literature. Estimates are for areal extent across the United States.



References

1. Singer, JW et al. *Journal of Soil and Water Conservation*, 62(5), 353-358, (2007).
2. Johnson, G.A. et al. *Weed Technology*, 7(2), 425-430, (1993).
3. Blanco-Canqui, H. et al. *Soil Science Society of America Journal*, 75(4), 1471-1482, (2011).
4. Poeplau, C. et al. *Agriculture, Ecosystems & Environment*, *200*, 33-41 (2015).
5. Lin, B.B. *BioScience*, *61*(3), 183-193, (2011).
6. Strock, J.S. et al. *Journal of environmental quality*, 33(3), 1010-1016 (2004).
7. Seifert, C.A. et al. *Environmental Research Letters*, 13(6), 064033 (2018).
8. Drinkwater LE and Snapp SS. *In: Advances in Agronomy. Elsevier*, 163–186. (2007)
9. Brummer E.C., et al. Plant breeding for harmony between agriculture and the environment. *Frontiers in Ecology and the Environment* 9:561–568 (2011).
10. US Department of Agriculture National Agricultural Statisics Service. 2017 Census of Agriculture. Chapter 2, Table 41 – Land Use Practice. Available at www.nass.usda.gov. Accessed November 5, 2019.
11. Wayman S., et al. *Renewable Agriculture and Food Systems*, 32(4), 376-385 (2017).
12. Mueller D.S., et al. *Plant health progress*, 17(3), 211-222 (2016).
13. Hellerstein D.M. *Land Use Policy*, 63, 601-610 (2017).
14. US Department of Agriculture, Farm Service Agency. Conservation reserve program monthly summary – September, 2019. Available at www.fsa.usda.gov. Accessed November 5, 2019.
15. Pretty J. et al. *Nature Sustainability*, 1(8), 441 (2018).
16. Tomei J. and Helliwell , R. *Land use policy*, 56, 320-326 (2016).
17. Ott M.A. et al. *Agronomy Journal*, 111(3), 1281-1292 (2019).
18. Runck B.C. et al. *Crop Science*, 54(5), 1939-1948 (2014).
19. JHarlan, J.R. et al. *Evolution* 27: 311–325 (1973).
20. Kantar M.B et al. *BioScience*, 67(11), 971-982 (2017).
21. Meyer, R.S. and Purugganan M.D. *Nature reviews* genetics, 14(12), 840 (2013).

Table S1. Yields and Seeding Rates of Commodity and Cover Crops.

	Maize Land Area in the USA acre in 2019	Maize Land Area in the USA hectare in 2019	Yield bu/acre	Yield kg/ha	Seeding Rate bu/acre	Seeding rate kg/ha	Total acres needed for seed production	Total hectares needed for seed production	Percentage of Maize acres needed for seed production	Number of acres planted from a single acre harvested	Number of hectares planted from a single hectare harvested
Maize	91700000	37125506	160	10043.2	0.39	24.4803	223519	90493.52227	0.24%	410	165.9919
Maize low	NA	NA	60	3766.2	0.39	24.4803	598597	242346.9636	0.65%	153	61.94332
Vetch low Yield	NA	NA	3.7	232.249	0.44	27.6188	10904865	4414925.101	11.89%	8	3.2388664
Vetch high Yield	NA	NA	12.5	784.625	0.44	27.6188	3227840	1306817.814	3.52%	28	11.336032
Oats low	NA	NA	58	3900.5	1.56	104.91	2470366	1000148.178	2.69%	37	14.979757
Oats high	NA	NA	78	5245.5	1.56	104.91	1836939	743700	2.00%	50	20.242915
Annual ryegrass low	NA	NA	39.6	2663.1	0.36	24.21	827020	334825.9109	0.90%	111	44.939271
Annual ryegrass high	NA	NA	51.1	3436.475	0.36	24.21	640900	259473.6842	0.70%	143	57.894737
cereal rye low	NA	NA	40	2690	1.79	120.3775	4093750	1657388.664	4.46%	22	8.9068826
cereal rye high	NA	NA	60	4035	1.79	120.3775	2729167	1104925.911	2.98%	34	13.765182
wheat low	NA	NA	66	4438.5	1.61	108.2725	2232955	904030.3644	2.44%	41	16.59919
wheat high	NA	NA	76	5111	1.61	108.2725	1939145	785078.9474	2.11%	47	19.02834
Triticale low	NA	NA	30	2017.5	1.61	108.2725	4912500	1988866.397	5.36%	19	7.6923077
Triticale high	NA	NA	80	5380	1.61	108.2725	1842188	745825.1012	2.01%	50	20.242915
Barley low	NA	NA	78	5245.5	1.56	104.91	1836939	743700	2.00%	50	20.242915
Barley high	NA	NA	108	7263	1.56	104.91	1326678	537116.5992	1.45%	69	27.935223
Buckwheat low	NA	NA	25	1681.25	0.8	53.8	2947500	1193319.838	3.21%	31	12.550607
Buckwheat high	NA	NA	35	2353.75	0.8	53.8	2105357	852371.2551	2.30%	44	17.813765

Flax low	NA	NA	30	2017.5	1.39	93.4775	4245370	1718773.279	4.63%	22	8.9068826
Flax high	NA	NA	50	3362.5	1.39	93.4775	2547222	1031263.968	2.78%	36	14.574899
Radish low	NA	NA	10.3	692.675	0.14	9.415	1271845	514917.004	1.39%	72	29.149798
Radish high	NA	NA	14.3	961.675	0.14	9.415	916084	370884.2105	1.00%	100	40.48583
Forage turnip low	NA	NA	23.8	1600.55	0.07	4.7075	275210	111421.0526	0.30%	333	134.81781
Forage turnip high	NA	NA	39.7	2669.825	0.07	4.7075	164987	66796.35628	0.18%	556	225.10121
Canola low	NA	NA	38	2555.5	0.09	6.0525	215461	87231.17409	0.23%	426	172.46964
Canola high	NA	NA	90	6052.5	0.09	6.0525	90972	36830.76923	0.10%	1008	408.09717
Mustard low	NA	NA	10.5	706.125	0.14	9.415	1247619	505108.9069	1.36%	74	29.959514
Mustard high	NA	NA	12.1	813.725	0.14	9.415	1082645	438317.8138	1.18%	85	34.412955
Crimson clover low	NA	NA	4.75	319.4375	0.27	18.1575	5171053	2093543.725	5.64%	18	7.2874494
Crimson clover high	NA	NA	7.05	474.1125	0.27	18.1575	3484043	1410543.725	3.80%	26	10.526316
Red clover low	NA	NA	8.55	574.9875	0.21	14.1225	2298246	930463.9676	2.51%	40	16.194332
Red clover high	NA	NA	15.4	1035.65	0.21	14.1225	1275974	516588.664	1.39%	72	29.149798
White clover low	NA	NA	7.94	533.965	0.14	9.415	1649874	667965.1822	1.80%	56	22.672065
White clover high	NA	NA	13.5	907.875	0.14	9.415	970370	392862.3482	1.06%	95	38.461538
Winter pea low	NA	NA	38.8	2609.3	0.89	59.8525	2110180	854323.8866	2.30%	43	17.408907
Winter pea high	NA	NA	77.5	5211.875	0.89	59.8525	1056452	427713.3603	1.15%	87	35.222672