Intercropping maize and Caucasian clover to reduce environmental impact of maize silage production

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Abstract

Maize (*Zea mays* L.) silage has become an increasingly important forage crop in high output dairy farming systems in Europe and North America because of its high energy density, relatively uniform nutritive value, and efficiency of production. But due to lack of surface residue and organic matter inputs and high nitrogen (N) fertilizer inputs, maize silage production is one of the most demanding cropping systems imposed on our soil and water resources. We investigated intercropping maize with the persistent rhizomatous legume, Caucasian clover (*Trifolium ambiguum* M. Bieb.), as a means to provide continuous living groundcover to minimize nitrate leaching, nutrient runoff and soil erosion. Maize was sown into existing stands of Caucasian clover that had been suppressed to reduce competition, and into areas with no clover. Total nitrate-N leached was reduced by 74% relative to the control monocrop maize under intercropped maize silage. On loess soils with 8 to 15% slope, during simulated, short, heavy rainstorms, Caucasian clover intercrop reduced water runoff by 50%, soil loss by 77%, and P and N losses by 80% relative to monocrop maize. Intercropping maize with Caucasian clover can eliminate N-fertilizer inputs and greatly reduce negative environmental impacts associated with maize silage production.

Keywords: *Trifolium ambiguum*, maize silage, nitrate leaching, soil erosion, phosphorus

Introduction

Maize silage is an important source of forage for dairy cattle in Europe and the USA because it is highly palatable, contains high energy density, produces high yields in a single harvest and has relatively uniform nutritional value. The cost per ton of dry matter is also typically much lower than for other mechanically harvested forage crops. Land area in maize silage is approximately 5.0 M ha in the EU and 3.0 M ha in USA. In Europe the area in maize silage is increasing as adapted hybrids become available and as demand increases to meet livestock and biofuel interests. In temperate climates maize for silage is a 5-month crop and for the remainder of the year fields lie dormant, radiation is not captured for photosynthesis, soil organic carbon is lost through respiration, the soil surface is unprotected increasing soil erosion and nutrient runoff, and nutrient-rich water is prone to leach out of the root zone. Biological intensification of maize silage production systems could mitigate some of these negative off-site impacts on surface water, ground water, and atmospheric greenhouse gases (Krueger *et al.*,2012). Our earlier work demonstrated that maize can be grown in suppressed Caucasian clover (Affeldt *et al.*, 2004; Zemenchik *et al.*, 2000) and that nearly the entire nitrogen requirement of the maize crop is met (Albrecht and Sabalzagaray, 2006; Berkevich, 2008). Caucasian clover initiates growth in early spring and recovers from suppression under the maize canopy and continues to grow into late autumn, extending time of soil surface cover by at least 2 months and maintaining a living root system year around. We explore some environmental impacts of such an intercropping system in this current paper.

Materials and methods

Experiment 1. Water and nitrate leaching research was conducted on silt loam soils near Arlington, WI (43°18' N, 89° 21' W) in fields sown to Caucasian clover 2 years earlier. Treatments in the 2.5-year experiment were N-fertilized no-till maize following killed Caucasian clover (control) and maize no-till sown into suppressed Caucasian clover receiving 0 or 90 kg N ha^{-1}. A water balance method (Ochsner *et al.*, 2010) and ceramic suction cup samplers were used to estimate water drainage, nitrate-N concentrations in soil solution below 1 m and calculate nitrate-N leaching.

Experiment 2. Water, soil, and nutrient runoff research was conducted on silt loam soils with 8 to 15% slope near Lancaster, WI (42°50' N, 90°48' W) in fields sown to Caucasian clover 2 years earlier. Treatments in this experiment were no-till maize following killed Caucasian clover (control) and maize no-till sown into suppressed Caucasian clover. Simulated rainstorms of 70 mm per hour were applied four times during the maize silage production season and once in spring following maize silage harvest. Water runoff and soil and nutrient concentrations in the runoff water were determined.

Results and discussion

For Experiment 1, data were separated into 6-month periods approximating the growing season (GS, April-September) and the dormant season (DS, October-March) (Table 1). The total nitrate-N leached under the intercropped maize-clover system with no added N was reduced 74% compared to the control. Total nitrate-N leached under the intercropped maize receiving 90 kg N ha^{-1} was reduced 31% relative to the control. Water drainage was similar across treatments (data not shown) so the observed large reductions in nitrate-N leaching were due primarily to lower nitrate-N concentrations below the intercropped maize-clover. The very large amount of leached nitrate-N in GS 3 is associated with 200 mm rainfall over an 8-day period. Negative values in GS 2 result from upward net water flow as roots took up water at depths greater than 1 m during a dry season. Nitrate-N concentration in leachate under intercropped maize with no N-fertilizer was never above 12 mg l^{-1}, whereas under the control system nitrate-N concentration was frequently above 40 mg l^{-1}. Similar concentrations of nitrate-N under conventional and intercropped maize were observed by Zemenchik *et al.* (2000), who noted that mineralization of N from decaying, supressed Caucasian clover seemed to be occurring at a rate adequate to meet the N demands of the growing maize crop.

In Experiment 2, the amount of time lapsing before water runoff occurred was always greater in maize intercropped with Caucasian clover compared to control maize (Table 2). This was associated with greater soil aggregate stability (data not sown) supporting greater water infiltration in the intercropping system. The combination of less runoff volume and lower amounts of suspended sediment in runoff resulted in less total soil loss from fields with maize intercropped with Caucasian clover compared to control maize. Total nitrogen and phosphorus lost from fields in runoff was associated primarily with runoff volume rather than concentration of nutrients in the runoff, and were always lower in the intercropped maize than in the control. Greater ground cover, greater soil aggregate stability, and greater infiltration were associated with less runoff of water, soil and nutrients in the maize-Caucasian clover intercrop than in control maize.

Table 1. Nitrate-N leached for three growing seasons (GS 1, 2, and 3) and two dormant seasons (DS 1 and 2) on silt loam soils at Arlington, Wisconsin.[1]

Treatment	Season					Total
	GS 1	DS 1	GS 2	DS 2	GS 3	kg N ha^{-1}
	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	
Maize	4	31	-13	50	80	151
Maize in clover + 90 kg N ha^{-1}	2	14	-6	36	57	104
Maize in clover + 0 N	2	8	-3	7	25	39

[1] The combination of data collection and modelling used to generate these values precludes statistical analysis.

Table 2. Runoff volume and content from plots with conventional maize silage or maize silage intercropped with Caucasian clover on silt loam with 8 to 15% slope which received simulated rainstorms of 70 mm per hour at Lancaster, Wisconsin.

Simulation date and cropping treatment	Time to runoff min.	Runoff volume l ha^{-1} (×1000)	Suspended sediment g l^{-1}	Total soil loss kg ha^{-1}	Total P loss kg ha^{-1}	Total N loss kg ha^{-1}
April, 2010						
Maize	7b	251a	7.40a	1,872a	0.92a	15.86a
Maize in clover	16a	94b	2.30b	209b	0.02b	1.26b
June, 2010						
Maize	8a	270a	9.68a	3,326a	1.12a	22.42a
Maize in clover	26b	59b	0.35b	29b	0.31b	0.83b
September, 2010						
Maize	3a	457a	11.50a	5,187a	1.24a	37.97a
Maize in clover	6b	335b	5.40b	1,816b	0.41b	11.93b
October, 2010						
Maize	5a	383a	6.53a	2,519a	0.49a	9.52a
Maize in clover	8b	248b	2.83b	688b	0.10b	3.50b
May, 2011						
Maize	5a	372a	3.00	1,100a	0.93a	9.77a
Maize in clover	19b	129b	3.55	450b	0.08b	1.87b

Within simulation period and column means followed by different letters are significantly different at P=0.05 according to Fischer's protected least significant difference.

Conclusions

Maize can be intercropped in a permanent field of Caucasian clover with maize silage yield similar to conventional production in seasons when soil moisture is not limiting. The Caucasian clover intercrop provided important environmental benefits, including reduced nitrate-N leaching, reduced soil erosion, and reduced nutrient loss in runoff. Thus this intercropping system has potential to improve sustainability of whole-plant maize harvest for silage. The concern of reduced maize silage yield during dry years is being addressed by incorporating 'drought tolerant' maize hybrids into the system.

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