How valuable is post-dispersal seed predation to control *Echinochloa crus-galli* in maize cropping in Mecklenburg-Western Pomerania?

Welchen monetären Wert hat der Fraß ausgefallener Samen von Echinochloa crus-galli *im Maisanbau Mecklenburg-Vorpommerns?*

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Abstract

Silage maize is an important arable crop in Germany. *Echinochloa crus-galli* is one of the main weed species in this crop. Herbicide treatment, a common practice by conventional maize farmers to control this weed, may cause many negative impacts on non-target species and the wider environment. Post-dispersal seed predation is an important ecosystem service for weed control, but its value is rarely known. To raise social awareness, we aim to estimate the economic benefits of this ecosystem service. The extent of benefits that farmers can receive from the post-dispersal seed predation depends greatly on how farmers control weeds.

By using an on-farm pesticide survey, the herbicide application patterns for *Echinochloa crus-galli* control in maize in the north-eastern Germany is analysed. Based on this, and by using economic surplus and field data from cage experiments, this case study estimated the value of post-dispersal seed predation of *Echinochloa crus-galli* in 2013 maize fields in Mecklenburg-West Pomerania. This represents one of the first attempts of economic valuation of this ecosystem service.

Key words: *Echinochloa crus-galli*, ecosystem services, post-dispersal seed predation, producer and consumer surplus, silage maize

Zusammenfassung

Silomais ist eine wichtige Kulturpflanze in Deutschland. In dieser Kultur ist *Echinochloa crus-galli* eine der Hauptunkrautarten. Für die Unkrautkontrolle im Mais gehört der Einsatz von Herbiziden zur gängigen Praxis, dies beeinflusst Nichtzielorganismen und die Umwelt jedoch negativ. Samenprädation gehört zu den wichtigen Ökosystemdienstleistungen, deren Wert innerhalb der Unkrautkontrolle jedoch unbekannt ist. Um das gesellschaftliche Bewusstsein für Ökosystemdienstleistungen zu steigern, ist es unser Ziel den wirtschaftlichen Nutzen dieser Leistung zu berechnen. In welchem Umfang Landwirte von den Samenprädatoren profitieren können, ist von der Unkrautkontrolle abhängig.

Es werden Anbaudaten landwirtschaftlicher Praxisbetriebe in Nordostdeutschland analysiert, um Muster in den Herbizidanwendungen zu charakterisieren. Ergänzt durch Daten aus einem Feldexperiment wird in dieser Fallstudie der wirtschaftliche Nutzen von Samenprädatoren für den Maisanbau 2013 in Mecklenburg-Vorpommern eingeschätzt. Diese Fallstudie repräsentiert die erste ökonomische Einschätzung der Ökosystemdienstleistung Samenprädation.

Stichwörter: *Echinochloa crus-galli*, Konsumenten- und Produzentenrente, Ökosystemdienstleistung, Samenprädation, Silomais

Introduction

Silage maize is a major arable crop grown in Germany, mostly cultivated for animal feed and now increasingly used in biogas production (DESTATIS, 2019). *Echinochloa crus-galli* (*E. crus-galli;* ECHCG, EPPO, 2018) is one of the most important weed species in this crop (DE MOL et al., 2015). German farmers mostly apply herbicides to control *E. crus-galli* in maize fields. However, *E. crus-galli* is the second most resistant weed species worldwide, and it has already been resistant to the ALS inhibitors in Germany (HEAP, 2018). There is thus a high risk for this species to develop further resistance in German maize fields. Unsustainable use of herbicides also causes negative impacts on human health, non-target species, and the wider environment (TAYLOR et al., 2006).

Besides herbicides, some animal species (i.e., granivory species among arthropods, birds and mammals) also contribute to weed reduction by feeding on the scattered seeds on the soil, thus reducing the volume of the soil seedbank. This ecosystem service is called post-dispersal seed

predation (SP), and field experiments have demonstrated its important role in weed demography (WESTERMAN et al., 2005). However, SP is little known in the society, either by farmers or policy makers. Estimating the economic benefits of an ecosystem service has been suggested as a method to quantify its contribution to human welfare, raise social awareness about its importance, and guide policy makers in supporting relevant conservation programs (COSTANZA et al., 2014). However, to the best of our knowledge, no successful attempt has been done on estimating the economic value of SP.
This case study aims to value the SP of *E. crus-galli* in maize fields in Mecklenburg-West Pomerania (M-V), a province in the northeast Germany. This paper represents a preliminary analysis based on the cropping conditions of 2013. The economic surplus method was applied, and data from northern Germany were used when they are not available for M-V.

Materials and Methods

Economic surplus method

Economic surplus method is recognised to value the economic benefits of various ecosystem services (e.g., biological aphid control, ZHANG et al., 2018). This method estimates the welfare value of price change to consumers and producers in a market setting. For this case study, the increased price of maize is caused by the potentially reduced supply of maize when SP is at a minimum. The supply shift parameter K is used here to measure the degrees of reduced maize supply, and the formula is as below:

$$\mathrm{K} = \mathrm{A} \times \frac{\text{relative yield reduction}}{\varepsilon} \qquad (1)$$

where A denotes the percentage of maize growing area in 2013 that have *E. crus-galli* infested and that also grew maize in 2012. The second condition is needed because SP functions in the previous year (2012), and we do not expect seeds of *E. crus-galli* on the soil without maize sowing in 2012. Relative yield reduction is the difference between the percentage yield reduction by *E. crus-galli* without SP and percentage yield reduction by *E. crus-galli* with SP. ε is the price elasticity of supply, which measures the percentage change in the maize quantity supplied by producers that results from a one percent change in its price. The price elasticity of demand is the analogous measure on the producers' side. The rest of the equations that estimate the producer and consumer surpluses are shown below:

$$Z = K\varepsilon/(\varepsilon + \eta) \qquad (2)$$
$$\Delta CS = ZQ_0P_0(1 + 0.5Z\eta) \qquad (3)$$
$$\Delta PS = Q_0P_0(K - Z)(1 + 0.5Z\eta) \qquad (4)$$
$$\Delta ES = \Delta CS + \Delta PS \qquad (5)$$

where η denotes the absolute value of the price elasticity of demand, Q_0 is the quantity of maize produced, P_0 is the price of maize, ΔCS the consumer surplus, ΔPS producer surplus, and ΔES economic surplus.
To calculate K, a key indicator to estimate is the relative yield reduction. This is derived from the common practice of local maize farmers to control *E. crus-galli*, i.e. herbicide application.

Herbicide application patterns to control *E. crus-galli* in maize

To understand how maize farmers use herbicides to control *E. crus-galli*, we used the on-farm pesticide dataset from ANDERT et al. (2018). From this dataset, we extracted the herbicide data that are potentially efficient against *E. crus-galli* in maize. In total, 29 farms from three north-eastern German regions (eight in Rostock, twelve in Fläming, nine in Oder-Spree) provided their herbicide data in maize from 2005 to 2014 (1,665 data points). The region Rostock is included in the province M-V. A preliminary estimate shows that the average annual application frequencies of herbicides to maize fields that can potentially control *E. crus-galli* are 1.1 in Rostock, 1.0 in Fläming, and 1.0 in Oder-Spree. This is also in line with the findings from JULIUS KÜHN-INSTITUT (2016), which shows that the average number of herbicide applications in German maize fields was about 1.31 to 1.47 in 2011–2015, including use of glyphosate.

This indicates that maize farmers typically apply one-time post-emergence herbicides in their fields to potentially control *E. crus-galli*. However, because of various limitations (e.g., weather conditions, herbicide efficacies), it is difficult for herbicides to eliminate *E. crus-galli* completely. This means that the remaining weeds in the fields may still compete with maize, and can potentially cause yield loss.

Relative yield reduction

To estimate the relative yield reduction, a key indicator to consider is the density of *E. crus-galli* in the maize fields after one-time herbicide application with and without SP.

First, we only look at the influence of SP to the density of *E. crus-galli*, and assume no herbicide application in the fields. The average density of *E. crus-galli* in maize fields with SP without herbicide application in 2013 is assumed to be 76 plants/m² (VON REDWITZ and GEROWITT, 2018). To estimate the density of *E. crus-galli* without SP, the data from cage experiments in maize fields were used (PANNWITT et al., in prep.). The experiments were installed on three conventionally managed maize fields in M-V. Treatments with different densities of *E. crus-galli* (300, 600, 1200, 2400 seeds m^{-2}) were established in a randomised design. Cages were permanently installed in all treatments to prevent the access of seed predators. The number of germinated seedlings per treatment were counted in spring and summer. The model estimated for these data is:

$$log_{10}(ECHCG\ density\ without\ SP) = -0.00001 \times (ECHCG\ density\ with\ SP)^2 + 0.008 \times ECHCG\ density\ with\ SP + 1.5 \quad (R^2=0.6) \qquad (6)$$

Then, the influence of one-time herbicide application to the density of *E. crus-galli* is considered in three scenarios: 1) we assume that the average herbicide efficacy to control *E. crus-galli* is 90%; 2) 95%; 3) 100%. Then the density of *E. crus-galli* with and without SP after one-time herbicide application is calculated (Tab. 1).

Following SPITTERS et al. (1989), which modelled the relationship between the maize dry yield loss and the density of *E. crus-galli*, the relative yield reduction is thus estimated (Tab. 1).

Results and Discussion

Based on the economic surplus method (Equation 1-5) and the estimated indicators (Tab. 1 and Tab. 2), the estimated economic benefits of SP are given in Table 3. The consumers refer to people who purchase silage maize from the producers (i.e. maize farmers). This case study estimated, for the first time, the economic benefits of weed seed predation in arable crops.

The results indicate that farm managements on weed control (in this case study, herbicides) have a great influence on the benefits farmers and consumers would receive from post-dispersal weed seed predators. This ecosystem service does have economic values as long as the average herbicide efficacy is less than 100%. This is likely to happen because of unfavourable weather conditions, mismatch of sensitive weed stages or weed plants protected by other plants tissues (GILL and GARG, 2014). Furthermore, it is in the future very probable that *E. crus-galli* develops more resistance to herbicides (HEAP, 2018). The consequence that the average herbicide efficacy goes down would increase the value of weed seed predation. Also, post-dispersal weed seed predators can feed on other weed seeds in the maize fields. Thus, if we look at their effects on multiple weeds, the total value of weed seed predation in Table 3 may increase accordingly. More work on this study is in progress. Other economic valuation methods that might be suitable to estimate this ecosystem service are developed. This case study focused on a German region, the valuation of different spatial scales will be examined. The weed density-crop yield model is an old reference, thus other suitable models will be explored in the literature. Furthermore, because of the limitation of data, sensitivity analyses will be conducted to take into account the potential variation in the value from the uncertainties of key indicators in the model.

Tab. 1 Relative maize yield reduction in 2013 in Mecklenburg-West Pomerania caused by a lack of post-dispersal seed predation to control *E. crus-galli* under three herbicide efficacy scenarios (following a one-time herbicide application).

***Tab. 1** Relativer Ertragsverlust im Maisanbau in Mecklenburg-Vorpommern 2013 beim Ausfall der Samenprädatoren bei der Regulierung von E. crus-galli in drei Szenarien zur Herbizidwirkung (nach einmaliger Applikation).*

Herbicide efficacy scenarios	ECHCG density with SP (plants/m²)	ECHCG density without SP (plants/m²)	Relative yield reduction (with-out/with SP) (%)
90%	7.6	11.4	0.3
95%	3.8	5.7	0.2
100%	0	0	0

Note: "SP" denotes the post-dispersal seed predation; Relative yield reduction is the difference between the percentage yield reduction by *E. crus-galli* without SP and percentage yield reduction by *E. crus-galli* with SP.

Tab. 2 The estimated values of indicators used for the economic surplus models.

***Tab. 2** Schätzwerte für die Modelindikatoren zur Berechnung der Renten.*

Indicators	Estimated values	Data sources
Maize yield	35.34 (t/ha)	www.regionalstatistik.de
Maize growing area	136,400 (ha)	www.regionalstatistik.de
Maize price	28 (€/t)	BÖCKER et al., 2018
A	11%	VON REDWITZ and GEROWITT, 2018
Absolute value of demand elasticity	0.24	FAPRI, 2016
Supply elasticity	0.08	FAPRI, 2016

Note: "A" denotes the percentage of maize growing area in 2013 that have *E. crus-galli* infested and that also grew maize in 2012. "SP" denotes the post-dispersal seed predation.

Tab. 3 The estimated economic benefits - expressed as producers and consumers surplus - of post-dispersal seed predation of *Echinochloa crus-galli* in 2013 maize in Mecklenburg-West Pomerania, Germany.

***Tab. 3** Wirtschaftlicher Nutzen, der Prädation von Samen von Echinochloa crus-galli in Maisfeldern in Mecklenburg-Vorpommern, Deutschland im Jahr 2013, unterteilt nach Produzenten- und Konsumentenrente.*

Herbicide efficacy scenarios	Economic benefits (€)	
	Producers	Consumers
90%	453,007	151,002
95%	228,357	76,119
100%	0	0

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