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Original Research Article

Modeling Yield Loss in a Tripartite Canola-Cover Crop-Weed System under Varying Nitrogen and Seeding Rates

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ABSTRACT

Possible use of cereal cover crops as a sustainable alternative weed control option in canola fields through optimizing cover crop and its density in canola-weed-cover cropping tripartite systems was modeled using a gamma density function with four parameters. The effect of competition between main crop (canola), cover crop (wheat or barley) and weeds on canola yield was studied in an experiment conducted in 2012/2013. Each cover crop was sown in four seeding rates: 0, 25, 50 and 75 percent under two nitrogen rates of 75 and 150 kg ha^{-1}. Weed suppression measured as canola relative yield was associated with the increase of seeding rate of cover crop according to a modified gamma density function. Parameters alpha, kappa, eta and lambda summarized the effect of N application on yield response under no cover crop conditions, measure of treatment effect on the curve amplitude, the plant density at which crop yield maximizes and the curve slope at the right tail which was an indication of the treatment effect on the rate of yield reduction beyond the seeding rate that maximized the crop yield, respectively. Model diagnostics and agreement analysis showed that the modified gamma density function described the functional response of the main crop to seeding rate of the cover crop equally well across a variety of treatment effects. Response curve analysis showed that in both levels of nitrogen, canola yield was more responsive to barley as cover crop when compared to winter wheat.

Keywords: Prediction, Modeling, Yield loss, Canola, Nitrogen, Yield components

Çeşitli Azot ve Ekim Oranları Altında Kanola-Örtü Bitkisi-Yabancı Ot Sisteminin Verim Kaybının Modellenmesi

ÖZ

Kanola arazilerinde yabancı otlar ile mücadelede tahılların örtü bitkisi olarak kullanımları ve kullanım yoğunluğu dört parametreli gama yoğunluk fonksiyonu kullanılarak modellenmiştir. 2012/2013 yıllarında ana bitki (kanola), örtü bitkisi (buğday veya arpa) ve yabancı otların birbiri ile yarışının kanola verimi üzerine etkisi çalışılmıştır. Her bitki dört farklı ekim sıklığı (% 0, 25, 50 ve 75) ve iki farklı (75 ve 150 kg ha^{-1} azot) ile ekilmiştir. Gama yoğunluk fonksiyonu ile kanolanın veriminin örtü bitkisinin ekim sıklığına bağlı olması durumundan yararlanılarak yabancı ot baskılanması hesaplanmıştır. Alfa, kappa, eta ve lambda parametreleri sırasıyla örtü bitkisi olmadığı durumda azotun verime etkisini, eğri üzerinde uygulamanın etkisini, ana ürün veriminin maksimum olduğu bitki yoğunluğunu ve uygulamanın verim kaybına etkisini gösteren eğriyi özetlemektedir. Modelleme sonucunda gama yoğunluk fonksiyonu ana bitkinin ekim sıklığına tepkisini tanımlayabilmiştir. Çalışma sonuçları, tüm azot seviyelerinde kanola veriminin arpaya buğdaydan daha fazla tepki gösterdiğini ortaya çıkarmıştır.

Anahtar Kelimeler: Tahmin, Modelleme, Verim kaybı, Kanola, Azot, Verim komponentleri

INTRODUCTION

Cover cropping is a vital practice for organic crop producers. It improves soil properties and has positive effects on crop development and yield (Sainju *et al*. 2002). Considerable research on the mechanisms of action of cover cropping on soil quality and harvested yield has proved positive effects of cover crops such as improved soil carbon sequestration, microbial biomass and microbial activities (Sainju *et al*. 2007). Cover cropping was shown to cause weed control in lettuce (Ngouajio *et al*. 2003). Alternative weed control strategies are particularly required under sustainable agricultural practices and evaluation of cover crops as a potential candidate for weed suppression is of prime importance. The use of cover crops is recognized as one of the best alternatives to herbicides particularly in organic farming systems that weed management without chemicals is a major challenge. Cover crops compete with weeds for vital resources such as light, soil moisture and nutrients (Zimdahl 1993). Several studies suggest the value of planting a single cover crop species in suppressing weeds and improving soil fertility, however the value of diverse cover cropping agriculture has received little attention (Batie 2003, Brennan and Smith 2005, Ngouajio *et al*. 2002, Kelsey *et al*. 2011). In general, the maximum requirement for nutrients and water by weeds occur at the same time as for competing crops (Zimdahl 1993).

Winter oilseed rape is a highly competent species and can suppress weeds after canopy closure particularly under conditions of high N-regimes. Despite this fact, protection of the crop from weeds is inevitable and may generally be practiced in combination with soil conservation or during early stages of growth. Leaf littering during ripening (BBCH 80–89) can result in a lower density canopy which allows weeds to grow and eventually implicate harvest at maturity and/or affect seed purity. Reduced N-supply was shown to delay canopy

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closure and thus the potential of oilseed rape to suppress weeds. According to Merkel *et al*. (2004), winter oilseed rape must be kept weed-free before canopy closure to avoid yield loss.

Importance of the role of increasing amount of nitrogen fertilizer in competitive ability of weeds and their impact on harvested yield of the crop was shown in several works (Suomela and Paatela 1962, Alkamper 1976, Almeida-Dominguez *et al*. 1991, Carlson and Hill 1985, Lintell-Smith *et al*. 1992). The positive effect of increased N fertilization on weed biomass in sparse cereal stands was shown but in dense populations added nitrogen favored cereal plants which indirectly led to reduction in growth of weeds (Ervio 1972). In treatments without cover crops in celery fields, weed biomass increased when greater amounts of fertilizer were applied and weed management was effectively improved by practicing cover cropping and lowering fertilizer inputs (Charles *et al*. 2006).

Rapeseed is a new oilseed crop in Iran and farmers rotate this crop with winter small grains every other year in the same land. Although intercropping main crop with a cover crop is one of the alternatives to herbicides, cover crops can suppress not only weeds but also the main crops (Hooks and Johnson 2001). Therefore, optimal use of cover crop for weed control without adverse effects on the growth of main crop is important. Weeds could be controlled effectively by sowing cover crops after planting main crops in organic farming systems in a snowy-cold region (Uchino *et al*. 2009). To reduce the growth suppression of the main crop by the cover crop, intercropping of the cover crop (seeding into an established vegetation of the main crop) is necessary to avoid or decrease the competition between the cover crop and the main crop (Abdin *et al*. 1998). Impacts of the cover crop on weeds largely depend upon the cover crop species and crop management (Barberi and Mazzoncini 2001); hence more information on cover crop characteristics (species, growth pattern) and management (plant density, sowing date, etc.) is required for successful inclusion of a cover crop in a weed management strategy (Barberi 2002). Crop: weed competition and weed community dynamics may also be altered by fertilization management. High fertilizer application is often advantageous to weeds, which are usually able to take up nutrients in earlier growth stages more rapidly and efficiently than the crops. This effect seems to turn into a competitive advantage only when initial weed stand density is high. Cover crop seeding rate affects rapeseed yield or the ability of cover crop to suppress the development of weed stands. Prevention of weed emergence is attained partly through competition for light, nutrients and soil moisture during the cover crop growing cycle. Interference from cover crops and their residues is related to their capacity to occupy ecological niches otherwise available for weed development.

Models are developed for many different purposes with description, understanding, prediction, comparison and communication as the most common ones (Schabenberger and Pierce 2001). Models have been widely used to predict weed population dynamics at the field level (Holst *et al*. 2007) and also to predict the interaction between weeds and different genotypes of cultivated plants (Paolini *et al*. 2006; Zhao *et al*. 2006a, 2006b, Wang *et al*. 2007). Modeling yield loss in weed-crop systems intercropped with cover crops can not only improve our understanding of how the outcome of complex competitive challenges in main crop-weed-cover crop system affect the crop yield, but also help prediction of optimal cover crop plant density for controlling weeds.

There are no studies on statistical modeling of yield loss in systems comprising main crop and both a cover crop and weeds. The objective of this study was to investigate the effect of cover cropping and fertilization on weed suppression and evaluate the performance of a modified gamma density function with the possibility to predict the optimum combination of cover crop seeding rate (as an indicator of plant density) as well as N fertilization rate by modeling relative yield response as a function of cover crop seeding rate.

MATERIALS AND METHODS

A field trial was conducted during 2012-2013 growing seasons at the Experimental Research Center of Shiraz University. Two levels of nitrogen (75 and 150 kg N ha^{-1}) and four levels of seeding rate (SR=0, 25, 50 and 75%) of each of the cover crops (C=wheat and barley) were randomly assigned to main, sub and sub-sub plots respectively in a split-split plot layout with three replications. Weed free plots were used as controls. Rapeseed (var. Talaye) was sown two cm deep in rows spaced 15 cm apart at a planting density of 70 plants m^{-2} using a pneumatic planter. Cover crops were also intercropped simultaneously as broadcast in late September after land was prepared. Preplant triple super phosphate (100 kg ha^{-1}) and additional nitrogen applications as topdressing were also supplemented at 6-leaf, stem elongation and flowering growth stages. Trifluralin (2 $L.ha^{-1}$) and Super Gallant (1 $L.ha^{-1}$) were used for weed control. Wheat and barley (cover crops) planting rates were calculated according to 200 and 150 kg ha^{-1} respectively to obtain their corresponding levels (25, 50 and 75%). Wheat and barley were grown until grain maturity. Each plot was harvested separately at the end of the growing season (late July), and biomass, yield components and grain yield were determined. Relative yield of the crop (yield of a certain plot/yield of its weed free plot control) was modeled as a gamma function of cover crop plant density by submitting the data to Proc NLIN of SAS software (SAS institute Inc., 1999). Weed suppression was related to the increase of relative yield of the main crop using a modified gamma function (Kolnaar and van den Bosch 2001, Mood *et al*. 1974) with four parameters (Eq. 1).

$$L = \kappa \frac{(x-\alpha)^{\eta-1} e^{-\frac{x}{\lambda}}}{\lambda \Gamma(\eta)} \quad \text{Eq. (1)}$$

Where x, α, and κ are the cover crop density, intercept (summarizes the treatment effect on yield response under no cover crop conditions), and shape parameter (determines the amplitude of the curve ~overall treatment effect) respectively. The other two shape parameters (λ and η) respectively measure the optimum cover crop density (where crop yield maximizes) and the slope of the curve at the right tail (indicating the treatment effect on yield reduction rate at densities greater than optimum cover crop density). To further verify the significance of the effects of treatments (N=Nitrogen, C=Cover Crop, SR=Seeding Rate) and their interactions on canola yield and its components, analysis of variance was also performed using Proc Mixed of SAS program (SAS institute Inc., 1999).

RESULTS AND DISCUSSION

A summary of the results of statistical analyses including agreement analysis and parameter estimates is presented in Table 1. The modified gamma density model used to describe the relationship between the relative yield of canola (the main crop) intercropped with wheat and barley (two species of cover crops), each at varying levels of seeding rates under different nitrogen levels showed an excellent fit to the data. The nonlinear model had very close to unity concordance correlation coefficients, highly precise and accurate (precision, accuracy and systematic bias near unity), and very near to zero constant bias (Figures 1-2 and Table 1). It predicted yield in experimental plots with extremely small constant biases (zero up to 4 decimal numbers) except for the plots of canola intercropped with barley and fertilized with 75 kg Nitrogen ha^{-1} with a very close to zero negative bias. It was shown that the number and dry weight of barley weeds after 60 and 90 days from sowing increased significantly as N-levels increased from 15 to 30, 45 and 60 kg /fed. The highest and lowest number and dry weight of weeds after 60 and 90 days were recorded under 60 and 15 kg N/fed respectively (El-Metwally *et al*. 2010). Similar results were observed in independent studies. (Turk *et al*. 2003, Blackshaw and Brandt 2008, Nassar 2008).

No scale shift was also evidenced in model predictions owing to very close to unity systematic biases. Perfect agreement only occurs when means of the observed and predicted values are equal, the variance of the observed and predicted values are identical and the covariance of the observed and predicted equals the variance. The overall fit of the gamma density function showed that this model had a high flexibility in simulating the pattern of functional response of the main crop (as measured by canola yield) in the new complicated canola-weed-cover crop system.

In all treatments relative yield of canola initially increased with cover crop density and reached to a maximum, then reduced steadily and reached its minimum thereafter as the seeding rate of the cover crop increased (Figure 1, see values of η Table 1). Application of higher rates of nitrogen increased the optimum cover crop density (η), irrespective of the cover crop. The optimum cover crop density was higher for barley (~16%) than that for wheat (13%) when 75 $Kg.ha^{-1}$ nitrogen was applied, however the trend reversed when the rate of nitrogen doubled (respectively 26 and 21% for wheat and barley). Planting barley as cover crop with 75 Kg ha^{-1} nitrogen (BN75) resulted in the highest relative yield of canola (97% of control) followed by WN75, BN150 and BN150 treatments (74, 67 and 60% of control respectively).

Split-split plot analysis of variance using Proc mixed of SAS also confirmed that treatments (N, C, SR) and their interactions (N*C, N*SR, C*SR, N*C*SR) significantly affected the seed relative yield of canola as main crop which is assumed as the eventual outcome of the complex interactions between the components of the tripartite system (Figure 1 and 2). Our results showed that the rate of N application had a significant effect on the intercept of the response curves as increasing N rate significantly decreased the relative yield of canola at all levels of cover crop seeding rate irrespective of the species of cover crop (Table 1, Figure 2). Response curve analysis showed that in both levels of nitrogen, canola relative yield was more responsive to barley as cover crop when compared to winter wheat. In spring barley fields with a normal seeding rate, it was shown that less than 5% of nitrogen in the above-ground biomass was accumulated in weeds, but in spring wheat stands the corresponding amount averaged 10-15% (Salonen 2009). Analysis of variance and mean comparisons also supported these findings and it was shown that canola yield was significantly higher when intercropped with barley.

Table 1. Parameter estimates and model diagnostics in predicting yield under different cover crop (wheat and barley) and varying rates of Nitrogen.

Reliability statistic	N=75 kg/ha		N=150 kg/ha	
	Barley	Wheat	Barley	Wheat
CCC[1]	0.9996	0.9994	0.9989	0.9979
precision[2]	0.9996	0.9994	0.9989	0.9979
accuracy	1.0000	1.0000	1.0000	1.0000
constant bias (u)	0.0000	-0.0013	0.0000	0.0000
systematic bias (v)	1.0004	1.0009	1.0011	1.0020
alpha	-1.4868	- 0.6602	-5.8484	-11.994
kappa	63.081	56.768	45.447	31.007
eta	1.5582	1.3010	2.0751	2.6244
lambda	31.626	44.805	29.349	24.781
Se[3] alpha	0.6322	0.7218	1.5858	3.4017
Se kappa	2.3751	2.6009	3.9928	6.5690
Se eta	0.0942	0.1023	0.1838	0.3780
Se lambda	1.9907	4.5406	2.5908	3.0241

[1] Concordance Correlation Coefficient, [2]Pearson Correlation Coefficient, [3]standard error

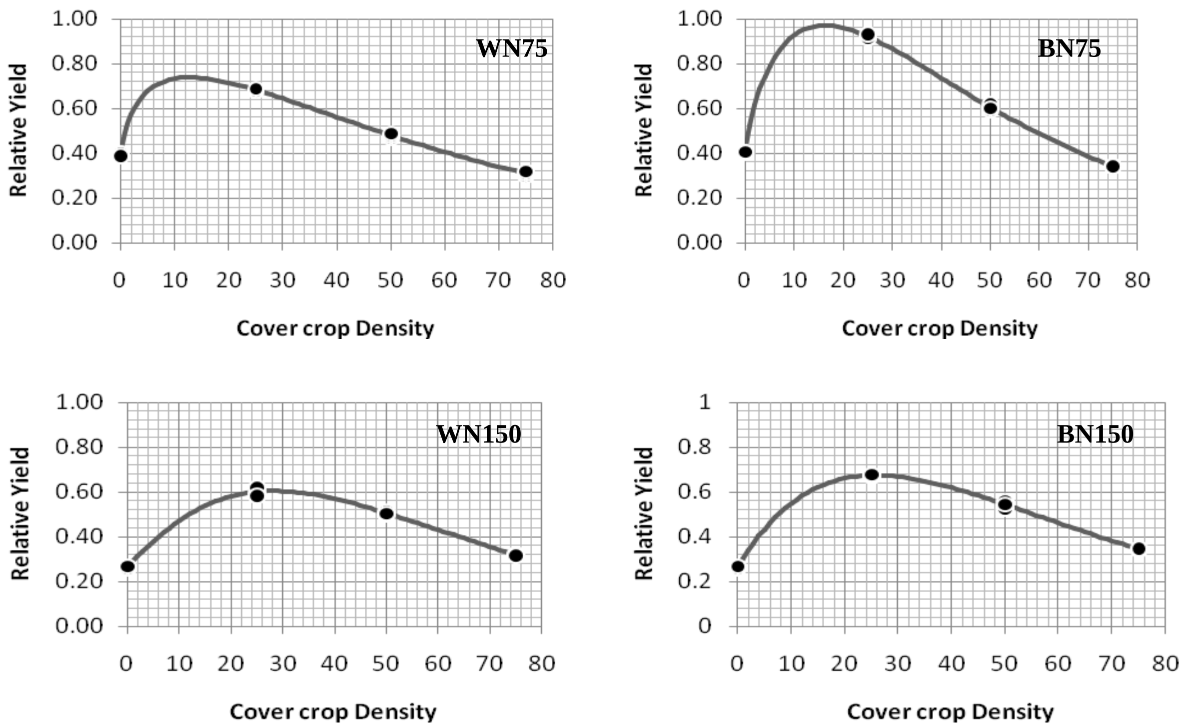
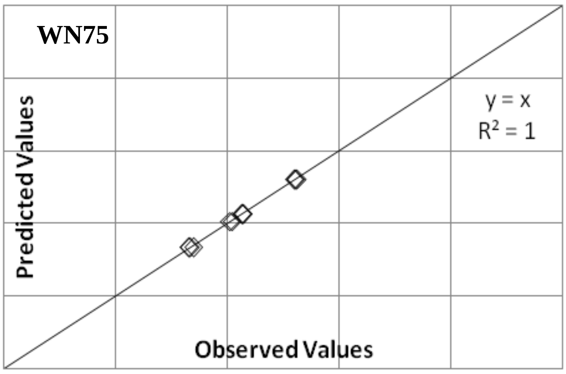
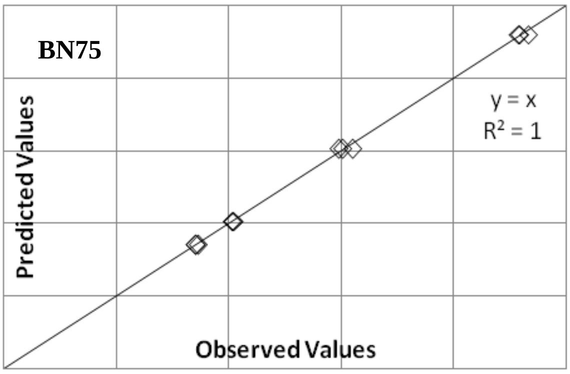


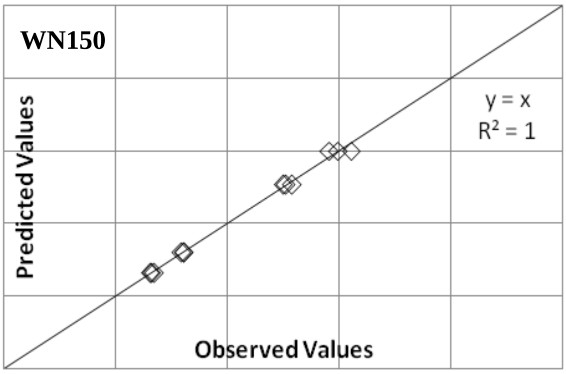
Figure 1. Relative yield determined as fraction of maximum yield in control (weed free plots). Solid points are observed relative yields and there are three observations in each cover crop density and continuous curves are best-fit gamma densities, WN75=Wheat + 75 Kg N ha-1; BN75=Barley +75 Kg N ha-1; WN150=Wheat + 150 Kg N ha-1; BN150=Barley +150 Kg N ha-1.



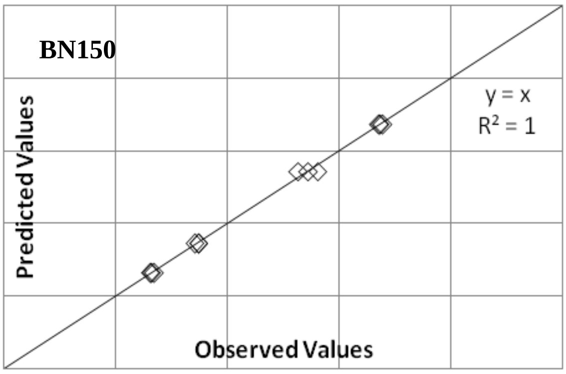
$\hat{y}$= -0.0002307 + 1.00033 × y
$adjR^2$=0.9987



$\hat{y}$= -0.00000590 + 1.00001 × y
$adjR^2$=0.9991



$\hat{y}$= 0.000009 + 0.99999 × y
$adjR^2$=0.9955



$\hat{y}$= 7.469803E − 7 + 1.0000 × y
$adjR^2$=0.9976

Figure 2. Graphical results of agreement between predicted (vertical axes) and observed relative yields (horizontal axes). The relationship between predicted ($\hat{y}$) and observed relative yield (y) is shown inside each graph with its corresponding $adjR^2$, WN75=Wheat+75 Kg N ha^{-1}; BN75=Barley +75 Kg N ha^{-1}; WN150=Wheat+150 Kg N ha^{-1}; BN150=Barley+150 Kg N ha^{-1}.

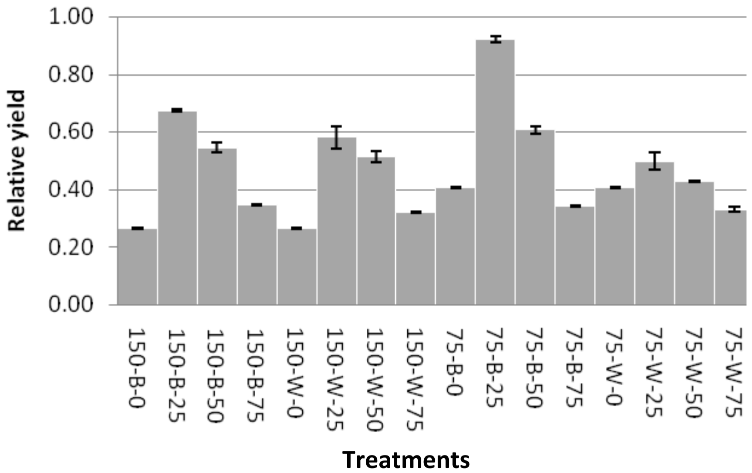


Figure 3. Comparison of means of canola yield in plots with 0, 25, 50 and 75% seeding rate of each of barley and wheat as cover crop fertilized with 75 and 150 kg/ha. Yield is expressed as a fraction of control (weed free and cover crop free for both levels of N). Key to decipher acronyms for the treatments is as follows: B=Barley, W=Wheat, C=Control (weed free), 75 and 150 are application rates of N in kg/ha. Bars are $\pm SEM$ (standard error of means).

CONCLUSION

Optimization of wheat and barley as cover crops and their densities under varying N application rates in as a sustainable alternative weed control option in canola fields was investigated. Robustness of a gamma density function with four parameters in modeling the canola-weed-cover cropping tripartite systems was evidenced. Response curve analysis showed that in both levels of 75 and 150 kg/ha of nitrogen, highest canola relative yield was observed in barley as cover crop, 75 kg/ha N and at 16% cover crop density. Significance efforts were made to relate model parameters to the effects of treatments.

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