J. Crop Prot. **2016, 5 (3): 389-395**
doi: 10.18869/modares.jcp.5.3.389

Research Article

Modeling of crop loss caused by *Puccinia striiformis* f. sp. *tritici* in three common wheat cultivars in southern Iran

Mohammad Reza Eslahi[1*] and Shideh Mojerlou[2]

1. Plant Protection Research Department, Khuzestan Agricultural and Natural Resources Research Center, AREEO, Ahvaz, Iran.
2. Department of Horticulture and Plant Protection, College of Agriculture, Shahrood University of Technology, Shahrood, Iran.

Abstract: Stripe rust cause by *Puccinia striiformis* f. sp. *tritici* is one of the most important diseases of wheat and can cause severe yield loss in many wheat growing regions of the world including Iran. To determine yield loss caused by this disease and evaluate the effect of some chemical components on reduction of yield loss in south of Iran, field experiments were carried out in split plot design with three replications at Ahvaz research station during 2014-2015. Three cultivars; Chamran, Virinak and Boolani, were used and artificial inoculation was performed using an isolate which was collected from south of Iran and designated as Yr27 race variant. Meanwhile the effects of propiconazole and some herbicides on yield loss reduction were studied. In this study, grain yield and area under disease progress curve (AUDPC) were measured. Statistical analysis showed that the level of the yield reduction was significantly different in the three studied cultivars and different treatments. Propiconazole could control the disease significantly. The highest yield loss was observed for cv. Boolani in both with (9%) and without (54%) fungicide treatments. Combined application of propiconazole and herbicides significantly reduced yield loss compared with using them separately. The results of crop loss modeling using integral and multiple point regression models showed that the integral model (L = 0.017AUDPC-17.831) could explain more than 69% of AUDPC variations in relation to crop loss in all cultivars. In multiple point models, disease severity at various dates was considered as independent variable and crop loss percentage as dependent variable. This model with the highest coefficient of determination had the best fitness for crop loss estimation. The results showed that the disease severity at GS39, GS45, GS50 and GS60 stages (Zadok's scale) were more important for crop loss prediction than those in other phenological stages.

Keywords: AUDPC, Crop loss, Modeling, Stripe rust, Wheat

Introduction

Wheat stripe rust (yellow rust) caused by *Puccinia striiformis* Westend f. sp. *tritici* Eriks. (*Pst*) is one of the most damaging diseases of wheat in Iran. Yield loss due to Stripe rust in most producing regions in the world is 10-70 % depending on the cultivar susceptibility, earliness of the initial infection, disease development rate and disease duration (Chen, 2005). Also, geographical location and environmental conditions affect the disease in crops (Jindal *et al.,* 2012). Yield loss due to yellow rust is reported to be about 30% of wheat production in 1992-93 in Iran (Tobari *et al.,* 1995).

The common way of rust diseases control is to use resistant cultivars. As is know, overcoming of

Handling Editor: Naser Safaie

* **Corresponding author**, e-mail: mr_eslahi@yahoo.com
Received: 12 April 2016, Accepted: 1 June 2016
Published online: 21 June 2016

resistance to stripe rust is very usual and occurs at regular intervals, therefore, management strategies are critical for minimizing losses in this situation. Loss estimation provides information for disease forecasting and finding a suitable management method (Campbell and Madden, 1990). Thus, the relation between disease and yield needs to be evaluated. Crop loss is a function of disease epidemics and one of the common ways to show this relation by linear regression which has two aspects including monovariate and multivariate (Madden, 1983). Madden (1983) used nonlinear regression model to show the relation between crop loss and disease severity. Weibull distribution is a type of nonlinear method which is a flexible model and has a good fitness with various shapes of curves (Teng, 1983). Crop loss modeling was studied by many researchers (Madden, 1983). The equation below shows a common crop loss model.

$$L = Y_0 - Y = b_0 + b_1x_1 + \ldots + c_1z_1 + \ldots + d_1x_1z_1 + \ldots$$

Where, L is difference of yield between treatment (Y) and control (Y_0) plots in the field experiments; x shows the disease incidence, disease severity, disease variation at several times or disease density at critical time; z is showing the yield characters or other variables like year, position and b, c and d are the parameters found from data (Zhang *et al*., 2007).

Three models including critical point model, multiple point model, area under rust progress curve model have been developed to estimate yield loss from disease severity data (James and Teng, 1979) e.g. wheat stem and leaf rust (Van der Plank, 1963; Buchenau, 1975). Buchenau (1970) introduced an area under disease progress curve (AUDPC) based model to predict rust loss and showed 1:1 relationship between rust progress curve and percentage of yield loss. Critical point relationships between yellow rust severity and yield loss have been calculated in UK (Mundy, 1972; King, 1976). Also, the relationships between stripe rust severity and grain yield loss in Victoria have been estimated using all three models mentioned above (Brown, 1988). Also, these models were used to evaluate the relationship between yield loss and disease severity in different diseases in Iran (Mojerlou *et al.*, 2009; Aghajani *et al.,* 2013).

In this study, yield losses of stripe rust in three common wheat cultivars were evaluated in southern Iran. Also, the impact of spray of propiconazole (Tilt ® 25 EC) fungicide and its combination with Atlantis®, sulfosulfuron (Apirus®) and 2,4-D on disease management and yield under disease pressure were studied.

Materials and Methods

To determine crop loss caused by yellow rust, three common wheat cultivars currently under production (Chamran, Virinak and Boolani) were sown at early December. An experiment was carried out in a Split Plot Design with three replications at Ahvaz Research Station during 2014-2015. Each cultivar was planted in plots of six rows, 3 m long and 1.2 m wide. The space between rows was 30 cm and within rows was 5 cm. Artificial inoculation was performed in March at tillering growth stages (GS37; Zadoks scale). One single spore isolate of *Puccinia striiformis* f.sp. *tritici* which was a derivative of Yr27 race, was used for inoculation. Four g of stripe rust spores was mixed with 20g talc powder and sprayed on wet leaves of susceptible cultivar (Boolani) which was planted around experimental plots to enhance disease development. Artificial inoculation was performed in March at tillering growth stages (GS37; Zadoks scale). The treatment without inoculation was considered as control. Some chemical treatments were considered to evaluate the impact of fungicide and its combination with herbicides on yield loss. These treatments included; Tilt® (0.5 l/ha), Tilt® (0.5 l/ha) + Atlantis® (1.5 l/ha), Atlantis® (1.5 l/ha), Tilt® (0.5 l/ha) + Apirus® (20g) + 2, 4-D (1.5 l/ha) + sitogate oil (1 l/ha), Apirus® (20g) + 2, 4-D (1.5 l/ha) + sitogate oil (1 l/ha). Chemical treatments were applied 2 weeks after fungal inoculation.

Stripe rust severity was assessed at 10-day intervals using modified Cobb scale (Peterson *et al.,* 1948) beginning from the time of disease appearance and area under disease progress curve (AUDPC) was calculated according to the equation (Campbell and Madden, 1990);

$$\text{AUDPC}=\sum_{i}^{n-1}\left(\frac{y_i+y_{i+1}}{2}\right)(t_{i+1}-t_i)$$

Grain yield was calculated for all cultivars and crop losses were calculated based on equation below (Milus, 1994);

$$\text{Crop loss}=\left\{1-\left(\frac{Yd}{Yh}\right)\right\}*100$$

Where, Y_h is the average of control yield and Y_d is the yield of each treatment. Duncan's multiple range test was performed for comparison of means of yield losses. Statgraphic software ver. 3 was used to calculate the parameters of integral and multivariate crop loss models.

Results and Discussion

There was a significant difference ($p \leq 0.01$) between cv. Boolani and other cultivars for yield loss. However, there was no significant difference between cvs. Virinak and Chamran (Fig. 1). The crop loss ranged from 25 to 55% without fungicide treatment. Tilt® could control disease significantly and reduced yield loss caused by *P.st* about 18% in examined cultivars (Fig. 1). Application of Atlantis® alone had no effect on yield loss, but when it was combined with Tilt®, could reduce yield loss significantly (Fig. 2). Also, there was no significant difference between Tilt® treatment and Tilt® + Atlantis® treatment. Therefore, in this case combination of fungicide and herbicide had no synergistic/ antagonistic effect on disease control (Fig. 2).

Other herbicides which were used in our study included, Apirus® and 2, 4-D. and Mix of these herbicides with Tilt®. Based on the results, mixture of Tilt® + Apirus® + 2, 4-D + sitogate oil could reduce yield loss significantly (Fig. 3). When Tilt used alone the yield loss was less than other treatments, then it was more successful. There was a significant difference between these two treatments in cvs. Boolani and Virinak. But yield loss was approximately similar in both treatments in cv. Chamran (Fig. 3).

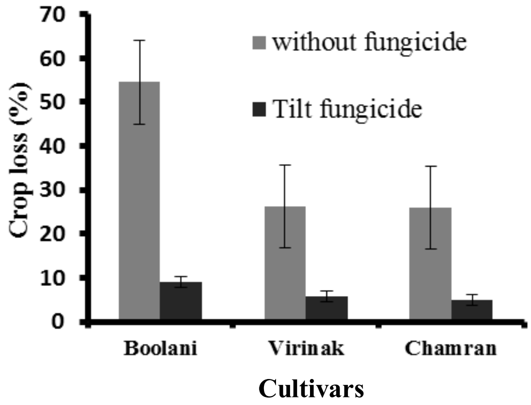

Figure 1 Comparison of crop loss due to *Puccinia striiformis* f. sp. *tritici* in three cvs. (left to right) Boolani, Virinak and Chamran in two treatments (with and without Tilt® fungicide).

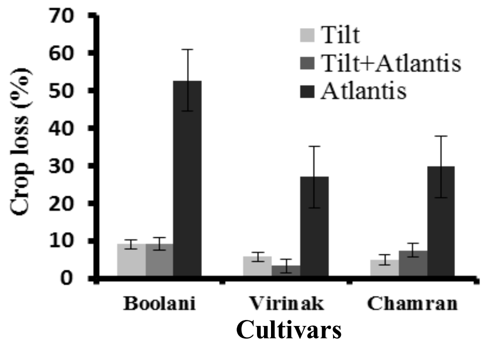

Figure 2 Comparison of crop loss due to *Puccinia striiformis* f. sp. *tritici* in three cvs Boolani, Virinak and Chamran treated with in Tilt®, Atlantis and Tilt® + Atlantis.

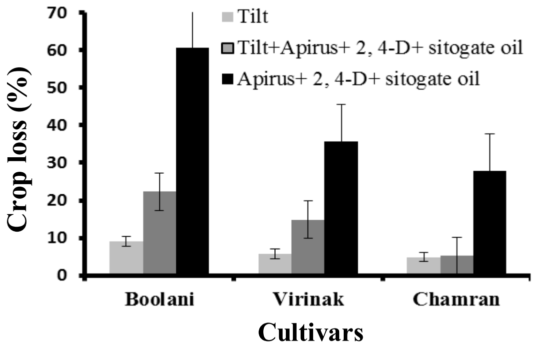

Figure 3 Comparison of crop loss due to *Puccinia striiformis* f. sp. *tritici* in three cvs. Boolani, Virinak and Chamran in Tilt®, Tilt® + Apirus® + 2, 4-D + sitogate oil and Apirus® + 2, 4-D + sitogate oil treatments.

The results showed the positive correlation between AUDPC and crop loss. Cv. Boolani which was susceptible to yellow rust showed the highest amount of AUDPC and yield loss. Cvs. Virinak and Chamran were in the second and third place, respectively. To develop a crop loss assessment model, AUDPC was considered as independent variable and crop loss (L) as dependent one in an integral model. Also, other functions of AUDPC such as logarithms and radicals were considered as independent variables. Table 1 shows the resulting models using data of all cultivars. When AUDPC was considered as independent variable, coefficient of determination (R^2) of the model was 68.89%. This model explained more than 68% of AUDPC variation against crop loss. Models included Ln (AUDPC) and $\sqrt{AUDPC}$ as independent variable, explained 62 and 66% of AUDPC variation against crop loss, respectively (Table 1).

When all disease severity records were considered in multivariate analysis, the best multiple point model was obtained as;

$$L = 0.122 - 0.404X_1 + 0.355X_2 + 0.687X_3 + 0.348X_4 + 0.690X_5 - 0.083X_6 - 0.411X_7 - 0.70X_8$$

Where X was the disease severity at different times of recording disease and including, X_1 and X_2, six leaf stage (GS37; Zadoks scale), X_3 and X_4 flag leaf opening (GS39), X_5 flag leaf extension (GS45), X_6, X_7 and X_8 earring (GS50) and flowering (GS60). The R^2 value was 95.85%, which indicated more than 95% of variability could be explained by this model.

To determine the most important phonological stages in crop loss assessment, the multivariate analysis was done for disease severity at different growth stages. The best obtained models are shown in Table 2. The results showed that X_4 (GS39), X_5 (GS45), X_6 (GS50), X_7 (GS50) and X_8 (GS60) were more efficient stages in crop loss assessment. Coefficient of determination of the model based on these stages was about 95%.

Though all the wheat varieties belong to the same *Triticum aestivum* L., species, highly significant differences were found among wheat yield as well as disease level (Afzal*et al.,* 2007). There are many models to show the relation between disease severity and yield. These models revealed that, the time of plant infection in relation to a given growth stage, has a major effect on the resulting yield (Madden *et al*., 2000). Crop loss is the function of disease epidemics and linear regression is a common way to show this relation (Madden, 1983).

Table 1 Crop loss model of wheat stripe rust caused by *Puccinia striiformis* f. sp. *tritici* in three cvs. Boolani, Virinak and Chamran.

Model	R^2	r	P-value
$L = 0.017AUDPC - 17.831$	68.89	0.83	< 0.001
$L = 38.90 Ln(AUDPC) - 276.43$	62.58	0.79	0.001
$L = 1.67\sqrt{AUDPC} - 56.85$	66.10	0.81	< 0.001

L, crop loss; AUDPC, area under disease progress curve; R^2, Coefficient of determination; r, coefficient of correlation.

Table 2 Crop loss multi point model of wheat stripe rust caused by *Puccinia striiformis* f. sp. *tritici* in three cvs. Boolani, Virinak and Chamran.

Model	R^2	P-value
$L = -3.11X_1 + 1.86X_2 + 1.25X_3 - 5.45$	90.61	< 0.001
$L = 0.69X_3 + 0.67X_4 + 0.87X_5 - 0.94X_6 - 0.84$	93.91	< 0.001
$L = 0.60X_4 + 1.04X_5 - 0.30X_6 - 0.45X_7 + 1.36$	94.60	< 0.001
$L = 0.525X_4 + 1.009X_5 - 0.243X_6 - 0.240X_7 - 0.22X_8 + 4.43$	94.95	< 0.001

L, crop loss; X, the disease severity at different times of recording disease; R^2, Coefficient of determination.

Single point model is a common type of linear regression method. In this model, x is considered as disease variable for predicting crop loss (y). Disease variable could be assumed as disease severity at a given special time (critical point), disease free days and Area Under Disease Progress Curve (AUDPC) or integral value (Teng, 1987).

Single point models have been used for several diseases including, corn leaf southern blight *Bipolaris maydis* (Gregory *et al*., 1978), potato late blight *Phytophthora infestans* (Olofson, 1968). Integral model was used for wheat stem rust *Puccinia graminis* crop loss assessment for the first time (Teng, 1987). Single point models have been developed for short time diseases which affect seed yield. In these models, crop loss assessment has been performed by using disease severity in one growth stage (Teng, 1987). Since stripe rust affects grain yield, using single point model is suitable for it. Our Results showed that, this model can explain 68% of AUDPC variation against crop loss.

Multiple point model is another type of crop loss assessment model. In this model, two or more disease recordings are used for crop loss assessment (Teng, 1987). Berleigh *et al.* (1972) presented the crop loss model caused by wheat stem rust *Puccinia graminis*. They used rust severity at three growth stages (Teng, 1987). In Multiple point model, increase of disease assessment data leads to improve models fitness. For example, in barley brown rust *Puccinia hordei*, when two growth stages were considered separately the model was justified for 72% of crop loss, but when they were considered together, 82% of crop loss was justified (Teng, 1987). Robert and coworkers (2004) presented prediction model for crop loss caused by *Septoria tritici* and wheat brown rust *Puccinia recondita*. Zhang and coworkers (2007) studied cultivar resistance and its effect on crop loss caused by four diseases (leaf septoriosis *Septoria tritici*, yellow rust *Puccinia striformis*, brown rust *Puccinia recondita* and powdery mildew *Blumeria graminis*.

Brown (1988) introduced a regression model for relation between stripe rust severity and grain yield loss. Results showed that the best indicator to estimate yield loss is disease severity at the end of anthesis-early berry growth stage (GS 68-71). A linear relation between yield loss percent and percentage of leaf area affected by stripe rust at GS37 has been revealed in NSW by Murray *et al.* (1987). Our results showed that GS39 to GS60 were the best indicators to evaluate yield loss and were in accordance with other researchers. Brown (1988) reported that critical point regression model is the most appropriate model for stripe rust yield loss prediction since it requires minimal input from the users of the system. Jindal *et al.* (2012) reported that spray of Tilt® 0.1 percent reduced the stripe rust disease in evaluated varieties, drastically. Our results agree well with their results.

The developed models in this study need further evaluations using more data on crop loss caused by *P. st* and may lead to a valid model for accurate crop loss prediction of this important disease in Iran.

References

Afzal, S. N., Haque, M. I., Ahmedani, M. S., Bashir, S. and Rattu, A. U. 2007. Assessment of yield losses caused by *Puccinia striiformis* triggering stripe rust in the most common wheat varieties. Pakistan Journal of Botany, 39: 2127-2134.

Aghajani, M. A., Safaie, N. and Alizadeh, A. 2013. Yield loss assessment of Sclerotinia stem rot of canola in Iran. Journal of Crop Protection, 2: 229-240.

Brown, J. S. 1988. Relationships between Stripe Rust Severity and Grain Yield Lass at Dooen, Victoria. Australian Journal of Agricultural Research, 39: 563-7.

Buchenau, G. W. 1970. Forecasting profits from spraying for wheat rusts. South Dakota Farm and Home Research Journal, 21: 31-34.

Buchenau, G. W. 1975. Relationship between yield loss and area under the wheat stem rust and leaf rust progress curve. Phytopathology, 65: 1317-1318.

Burleigh, J. R., Roelfs, A. P. and Eversmeyer, M. G. 1972. Estimating damage to wheat caused by *Puccinia recondite tritici*. Phytopathology, 62: 944-946.

Campbell, C. L. and Madden, L. V. 1990. Introduction to Plant Disease Epidemiology. John Wiley and Sons, 532 pp.

Chen, X. M. 2005. Epidemilogy and control of stripe rust (*Pucciniastriiformis*f.sp. *tritici*) on Wheat. Canadian Journal of Plant Pathology, 27: 314-37.

Gregory, L. V., Ayers, J. E. and Nelson, R. R. 1978. Predicting yield losses in corn from southern corn leaf blight. Phytopathology, 68: 517-521.

James, C. W. and Teng, P. S. 1979. The quantification of production constraints associated with plant diseases, In: Coaker, T. H. (Ed.), Applied Biology. Vol. IV, Academic Press, London, pp. 201-267.

Jindal, M. M., Sharma, I. and Singh, B. N. 2012. Losses due to stripe rust caused by *Pucciniastriiformis*in different varieties of wheat. Journal of Wheat Research, 4: 33-36.

King, J. E. 1976. Relationship between yield loss and severity of yellow rust recorded on a large number of single stems of winter wheat. Plant Pathology*,* 25: 172-7.

Madden, L. V. 1983. Measuring and modeling crop losses at the field level. Phytopathology, 73: 1591-1596.

Madden, L. V., Hughes, G. and Irwin, M. E. 2000. Coupling disease-progress-curve and time- of- infection for predicting yield loss of crop. Phytopathology, 90: 788-800.

Milus, E. A. 1994. Effect of leaf rust and Septoria leaf blotch on yield and test weight of wheat in Arkansas. Plant Disease, 78: 55-56.

Mojerlou, Sh., Safaie, N., Alizadeh, A. and Khelghatibana, F. 2009. Measuring and modeling crop loss of wheat septoria leaf blotch in seven cultivars and lines in Iran. Journal of Plant Protection Research, 49: 284-288.

Mundy, E. J. 1973. The effect of yellow rust and its control on the yield of Joss Cambier winter wheat. Plant Pathology, 22: 171-6.

Murray, G. M., Ellison, P. J., Watson, A. and Wratten, K. A. 1987. Stripe rust development, yield losses and fugicidal control in wheat in southern NSW. Proceedings of 6th Australian Plant Pathology Society conference, Adelaide, South Australia, p. 98.

Olofsson, B. 1968. Determination of the critical injury threshold for potato late blight (*Phytophthora infestans*). Statens Vaxtskyddsanstalk (Stockholm), 14: 85-93.

Peterson, R. F., Campbell, A. B., Hannah, A. E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. Canadian Journal of Research, 26: 496-500.

Robert, C., Bancal, M. O., Nicolas, P., Lannou, Ch. and Ney, B. 2004. Analysis and Modeling of effects of leaf rust and *Septoria tritici* blotch on wheat growth. Journal of Experimental Botany, 55: 1079-1094.

Teng, P. S. 1983. Estimating and interpreting disease intensity and loss in commercial fields. Phytopathology, 73: 1587-1590.

Teng, P. S. 1987. Quantifying the relationship between disease intensity and yield loss, In: Teng, P. S. (Ed.), Crop loss assessment and pest Management. APS Press, pp. 105-113.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A. R., Ramai, M. A., Golzar H. and Kashani, A. S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. Cereal Rusts and Powdery Mildews Bulletin, 23: 9-12.

Van Der Plank, J. E. 1963. Plant diseases: epidemics and control. Academic Press, New York. 349 pp.

Zhang, X. Y., Loyce, C., Meynard, J. M. and Monod, H. 2007. Modeling the effect of cultivar resistance on yield losses of winter wheat in natural multiple disease conditions. European Journal of Agronomy, 26: 384-393.

مدل‌سازی برای تعیین خسارت ناشی از قارچ *Puccinia striiformis* f. sp. *tritici* عامل بیماری زنگ زرد در سه رقم گندم نان در جنوب ایران

محمدرضا اصلاحی[1]* و شیده موجرلو[2]

۱- بخش تحقیقات گیاه‌پزشکی مرکز تحقیقات کشاورزی و منابع طبیعی خوزستان، سازمان تحقیقات آموزش و ترویج کشاورزی، اهواز، ایران.
۲- گروه باغبانی و گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه صنعتی شاهرود، شاهرود، ایران.
* پست الکترونیکی نویسنده مسئول مکاتبه: mr_eslahi@yahoo.com
دریافت: ۲۴ فروردین ۱۳۹۵؛ پذیرش: ۱۲ خرداد ۱۳۹۵

چکیده: زنگ زرد که توسط قارچ *Puccinia striiformis* f. sp. *tritici* ایجاد می‌شود یکی از مهم‌ترین بیماری گندم است و می‌تواند موجب کاهش شدید عملکرد در بسیاری از مناطق کشت گندم جهان ازجمله ایران شود. برای تعیین کاهش عملکرد ناشی از این بیماری و بررسی اثر برخی از ترکیبات شیمیایی در کاهش افت عملکرد گندم ناشی از این بیماری در جنوب ایران، آزمایش مزرعه‌ای در قالب طرح کرت‌های خرد شده با سه تکرار در ایستگاه تحقیقات اهواز در طول سال زراعی ۱۳۹۴-۱۳۹۳ انجام شد. در این آزمایش سه رقم؛ چمران، ویریناک و بولانی، مورد استفاده قرار گرفتند و آلوده‌سازی مصنوعی با استفاده از یک ایزوله که از جنوب ایران جمع‌آوری شده و به‌عنوان نژاد Yr27 شناخته می‌شود، صورت پذیرفت. در همین حال اثرات قارچکش پروپیکونازول و برخی از علف‌کش‌ها در کاهش افت عملکرد مورد مطالعه قرار گرفتند. در این مطالعه، عملکرد دانه و سطح زیر منحنی پیشرفت بیماری (AUDPC) اندازه‌گیری شد. تجزیه و تحلیل آماری نشان داد که سطح کاهش عملکرد در سه رقم مورد مطالعه و تیمارهای مختلف به‌طور قابل‌توجهی متفاوت بود: بالاترین کاهش عملکرد برای رقم بولانی چه در تیمار با قارچکش (۹ درصد) و چه در تیمار بدون قارچکش (۵۴ درصد) مشاهده گردید. استفاده از پروپیکونازول توأم با علف‌کش هم اثر قابل‌توجهی در کاهش افت عملکرد در مقایسه با استفاده از آنها به‌طور جداگانه نشان داد. نتایج حاصل از مدل‌سازی برای تعیین کاهش محصول با استفاده از مدل‌های انتگرالی و رگرسیون چندنقطه‌ای نشان دادکه مدل انتگرال ($L = 0.017AUDPC - 17.831$) می‌تواند بیش از ۶۹ درصد از تغییرات AUDPC در رابطه با از دست دادن محصول در تمام ارقام را توضیح دهد. در مدل‌های چندنقطه، شدت بیماری در تاریخ‌های مختلف به‌عنوان متغیرهای مستقل و درصد از دست دادن محصول به‌عنوان متغیر وابسته درنظر گرفته شد.این مدل با بالاترین ضریب تعیین، بهترین تناسب را برای برآورد خسارت داشت. نتایج نشان داد که شدت بیماری در مراحل GS39، GS45، GS 50 و GS60 (مقیاس Zadoks) برای پیش‌بینی از دست دادن محصول نسبت به سایر مراحل دیگر رشد مهم‌تر بود.

واژگان کلیدی: گندم، زنگ نواری، مدل‌سازی، خسارت، AUDPC