Efficacy of herbicides on crabgrass in Golf Course, Southern China

L Fei\textsuperscript{1,2,3} and P Jiang\textsuperscript{1}  
\textsuperscript{1}Zhuhai College of Jilin University, Zhuhai City, China  
\textsuperscript{2}Shanghai Jiao tong University, Shanghai City, China  
E-mail: 14270088@qq.com

Abstract. Crabgrass, a malignant weed on golf turf, affects the hitting effect and golf course landscape. In this study, three herbicides were used for crabgrass in driving range of the golf course in Southern China. Metsulfuron-Methyl, Flazasulfuron and Quinclorac were sprayed at three concentration gradients of 1, 2 and 3 times respectively. Results showed that three times the recommended amount of quinclorac had the best killing effect on crabgrass and the other two herbicides were still unsatisfactory even if the concentration reached three times of the recommended amount. The efficacy of quinclorac at recommended dose is 2.2 times higher than that of metsulfuron-methyl, and 1.3 times higher at three times recommended dose. Because this experiment was carried out in November, the leaf and sheath of crabgrass is old, cellulose content is high, lignification is serious, and it has high resistance to chemical herbicides. Manual removal is more environmentally friendly and efficient method.

1. Introduction  
A standard 18-hole golf course generally covers an area of about 67 hm, and the turf planting area in the whole golf course accounts for about 2/3 of the total golf course area. The golf course turf grass is a kind of functional lawn which is planted at one time and used for many years, and needs to be highly managed artificially in the process of using. The growth of weeds is the main cause of turf degradation. Sun [1] pointed out that the weeds destroy the uniformity of the lawn, not only affect the beauty of the course, but also compete with the planted turfgrass. Among all kinds of harms faced by turfgrass planted on golf course, the harm of weeds is the greatest threat to lawn.

Crabgrass is the most serious invasive weed in the golf course. At present, crabgrass grows in the fairway and rough area of the whole golf course, the most serious area is the fairway. Crabgrass (Digitaria Sanguinalis (L.) Scop.), an annual herbaceous plant of Digitaria Scop in the grass family, is wet, fertile and light-loving. It does not require strict soil requirements and can grow well in weak acid and alkaline soils. It has the characteristics of fast propagation, strong fecundity, fast growth and many tillerings. Turner and Van Acker [2] observed that more than 700 m\textsuperscript{2} of crabgrass seedlings emerged on some residential lawns in Canada in the last two weeks of July.

Especially in loose, wet and fertile areas, it is often the most prosperous breeding area of crabgrass. The planting layer of golf course turf is soft sandy soil, and for the healthy growth of turfgrass, it is necessary to keep the soil moist all the year round. At the same time, the greenkeeper will fertilize the turf from time to time. These characteristics of the soil that coincide with the life habits of crabgrass in the course.

Johnson [3] showed that the management of crabgrass was 99% with using ansar at 2.2 kg and
dithiopyr at 0.3 kg. He also found that after 2.2 kg of ansar, the control effect of 1.1 kg of dinitrotoluidine and 1.1 kg of oxadiazon reached 95% and 94% respectively. However, if the ansar is not used first, the control effect is less than 79% when the dinitrotoluidine or oxadiazon is used alone. Smith [4] used norflurazon from 0.56 to 1.68 liters to control crabgrass in Bermuda grass lawn. The effect was over 99%. However, when the dosage of norflurazon exceeded 1.68 liters, Bermuda grass lawn showed toxicity. Jeffery [5] found that crabgrass of golf course in New Jersey resistant to oxazol and chlorpyrifos, while in the rough area, it was sensitive to oxaprop. When crabgrass emerged, Fenoxyprop-P consumption was 0.76 kg/ha, which was 4 times the maximum, the biomass of the resistant crabgrass could be reduced by 35%, when the dosage was 1.52 kg/ha, 8 times the maximum. The biomass of crabgrass was reduced by 64%. It is evident that the efficacy of herbicides in general dosage is limited. The amount of herbicide is less than the effect of weed control, and the amount of herbicide is more harmful to turfgrass. Therefore, for chemical weed control of turf weeds, not only the choice of herbicide species, but also the amount of precise control.

2. Materials and methods

2.1. Test subjects
Zhuhai City is located in north latitude 21°48'-22°27', longitude 113°03'-114°19', and has a typical subtropical monsoon maritime climate, which annual average temperature is 22.5°C, annual average relative humidity is 80%, and the average annual rainfall of 206.9 mm. Gulf golf course is located in Zhuhai City, Guangdong Province. It is the first high standard 27-hole championship course designed by Colin Montgomerie in mainland China in 2003. The total area of the course is about 2.5 km². The total length of the fairway area is 6532 m. The turf area is about 49000 m² and the planting layer are sand and coarse sand. The turfgrass planted in fairway area, rough area and driving range is Seashore Paspalum grass. This experiment was conducted in a real grass driving range, which has the same maintenance measures as the fairway and the rough in irrigation and fertilization.

2.2. Test design
Nine square areas with an area of 1×1 m² were selected in the test area of Gulf golf course. Three herbicides namely Metsulfuron-Methyl, Flazasulfuron and Quinclorac, were used to dissolve the herbicide solution according to the recommended dosage in the product instructions, and it was set to the standard concentration. Prepared herbicides liquids were sprayed by spot-spray in all the tested areas at using three concentrations of each herbicide. This experiment is divided into three concentration gradients: 1-, 2- and 3-fold of recommended dosage. The experimental area with 1-fold recommended dosage was sprayed with three herbicides once, the experimental area with 2-fold recommended dosage was sprayed three herbicides twice, and the experimental area with 3-fold recommended dosage was sprayed three herbicides three times. The experiment was repeated three times and the average value was determined.

Before spraying the tested herbicides, the shoots number of crabgrass and the leaf age in the experimental area was recorded. No water was allowed within 12 hours after spraying herbicides. The first observation was made 24 hours later. The yellowing degree and dead area of each plant were recorded. Then every 2 days, the observation was made and recorded for 30 days.

2.3. Data processing of test
The obtained data were analyzed using Excel 2013 according to Neil and Mack [6].

3. Results and discussion

3.1. Effect of metsulfuron-methyl on the control of crabgrass
Table 1 is based on the ratio of the number of dead shoots to the total number of shoots in the experimental area of after metsulfuron-methyl herbicide was sprayed. It can be seen from the table 1
that the first spraying started on November 17, and on November 18, the next day, no shoots death occurred in the test area using metsulfuron-methyl recommended dosage, while the same number of shoots died in the test area using 2 times recommended dosage and 3 times recommended dosage. Three days after spraying, the death of the shoots of crabgrass was found in all of the test areas. From Nov. 18 to Nov. 26, that is, one week after spraying, the death peak period of the shoots of crabgrass was observed. The number of dead shoots in three testing dosages of the metsulfuron-methyl showed a straight upward trend. The results showed that metsulfuron-methyl had the best killing effect on crabgrass after 1 week of application. It can also be seen from the table 1 that there is almost no new increase in the number of dead shoots of crabgrass in the period from the eighth day to the half month after spraying. That is to say, the killing effect of metsulfuron-methyl on crabgrass is greatly reduced after spraying one week. The killing effect of standard dose of metsulfuron-methyl on crabgrass is much lower than that of two- or three-times standard dose. It was also found that the killing effect of 3-fold standard concentration was better than that of 2-fold standard concentration. As far as metsulfuron-methyl is concerned, it was found that there was a certain degree of chlorosis of seashore paspalum grass in the test area with three times the standard concentration. When using herbicides to kill crabgrass, we should not only request high efficacy of herbicides, but also evaluate the damage of herbicides to turfgrass (mainly chlorosis of grass leaves).

### Table 1. Number of dead shoots after spraying metsulfuron-methyl.

| Dose                  | Days |  |  |  |  |  |  |  |  |
|-----------------------|------|---|---|---|---|---|---|---|---|
|                       | 0    | 1 | 2 | 4 | 6 | 8 | 10| 12| 14|
| 1 recommended dose    | 0    | 0 | 0.3 | 1.3 | 1.6 | 2 | 2.3 | 2.3 | 2.3 |
| 2 times               | 0    | 0.3 | 1 | 1.6 | 2.3 | 3 | 4 | 4 | 4 |
| 3 times               | 0    | 0.3 | 1.6 | 2.3 | 3.6 | 4 | 5 | 5 | 5 |

On the 10th day after metsulfuron-methyl was applied, the number of dead shoots of crabgrass reached the peak, and there were no new dead leaves. One week later, on December 5th, new leaves of crabgrass were germinated in the experimental area using 1 and 2 times standard concentrations of metsulfuron-methyl. Only in the experimental area at applied this treatment 3 times, there were no new leaves of crabgrass. However, by December 6, the experiment area using 3 times of standard concentration also began to young leaf germinate. From Dec. 7 to Dec. 13, the number of the new leaf of crabgrass reached its peak. The results showed that after spraying by metsulfuron-methyl for 20 days, the killing efficacy was completely lost, and the tillers of crabgrass which had not been completely killed would germinate into new leaf again. Generally speaking, the inhibitory effect of 3-fold of standard concentration on the growth of crabgrass was better than that of 2-fold of standard dose and at applied one time of standard dose.

### Table 2. Number of germinating crabgrass leaves after spraying metsulfuron-methyl.

| Dose                  | Days | 17 | 19 | 21 | 23 | 25 | 27 | 29 |
|-----------------------|------|----|----|----|----|----|----|----|
| 1 recommended dose    | 1    | 1.5 | 2 | 2.5 | 3 | 3 | 3 |
| 2 times               | 1    | 1 | 1.3 | 1.6 | 2.3 | 2.3 | 2.3 |
| 3 times               | 0    | 1 | 1.3 | 1.6 | 2 | 2 | 2 |

3.2. Effect of flazasulfuron on the killing of crabgrass

Table 3 is based on the ratio of the number of dead shoots to the total number of shoots in the experimental area after the application of flazasulfuron herbicide. As can be seen from the table 3, the 10 days from the second day of flazasulfuron spraying, that is, from November 18 to November 28, are
the best time for flazasulfuron to kill crabgrass. Using of flazasulfuron at standard concentration three times had the fastest effect and the best efficacy, however, even if it was used at 1-fold standard concentration, the killing effect was better, because the number of dead shoots after spraying the standard concentration of the herbicide one time was similar to those standard doses which applied two or three times. It can also be seen from the table 3 that the efficacy period of flazasulfuron controlling crabgrass is 10 days. Compared with metsulfuron-methyl, the efficacy period lasts longer. It can be seen that the control effect of flaza Sulfuron on crabgrass is better than metsulfuron-methyl. After 28 November, the number of dead shoots did not increase, indicating the end of the effective period of flazasulfuron.

Table 3. Number of dead shoots after spraying flazasulfuron.

| Dose           | Days |
|----------------|------|
|                | 0    | 1    | 2    | 4    | 6    | 8    | 10   | 12   | 14   |
| 1 recommended dose | 0    | 0.3  | 1    | 2.3  | 2.6  | 3    | 3.6  | 3.6  | 3.6  |
| 2 times        | 0    | 0.6  | 1.6  | 2.5  | 3    | 3.6  | 4    | 4    | 4    |
| 3 times        | 0    | 1    | 2    | 3.3  | 4    | 5    | 5.3  | 5.3  | 5.3  |

Table 4. Number of germinating crabgrass leaves after spraying flazasulfuron.

| Dose           | Days |
|----------------|------|
|                | 17   | 19   | 21   | 23   | 25   | 27   | 29   |
| 1 recommended dose | 1    | 1.3  | 1.6  | 2    | 2.5  | 2.5  | 2.5  |
| 2 times        | 1    | 1.3  | 1.6  | 1.8  | 2    | 2    | 2    |
| 3 times        | 0.3  | 0.5  | 1    | 1.3  | 1.6  | 1.6  | 1.6  |

According to table 4, on Nov. 28, 10 days after flazasulfuron spraying, the killing effect of crabgrass reached its peak, and the number of dead shoots of crabgrass did not increase in the next 7 days. However, since Dec.5, new leaves have germinated more or less in all the experimental areas, which lasted until Dec.13. New leaves have continued to germinate in succession, indicating that flazasulfuron, as an herbicide, has completely lost its efficacy in killing crabgrass after 17 days of application. However, compared with metsulfuron-methyl, flazasulfuron could inhibit the germination of crabgrass. There are only 1.6 germinated leaves one month after the application of 3 times dose flazasulfuron, however, 2 new leaves were germinated under the condition of metsulfuron-methyl. Because the time limit of the experiment to Dec.13 did not continue to increase the newly leaves, it was not entirely herbicide effect, to some extent, also affected by the weather.

3.3. Effectiveness of quinclorac in the control of crabgrass

Table 5 is based on the ratio of the number of dead shoots to the total number of shoots in the experimental area after spraying quinclorac herbicide. It can be seen that the efficacy of quinclorac is the best from Nov. 18 to Nov. 28 beginning from after sprayed the next day. Even if it is used according to the standard concentration dose, the killing effect of quinclorac is also good. Comparing the efficacy of the three herbicides, it can be seen clearly that quinclorac has the best killing effect on crabgrass. After spraying quinclorac, the number of dead shoots of crabgrass was larger, and in the process of herbicide efficacy observation, it was found that quinclorac was the least harmful to turfgrass, and chlorosis of seashore paspalum grass leaves was not obvious.

Table 5. Number of dead shoots after spraying the quinclorac.

| Dose           | Days |
|----------------|------|
|                | 0    | 1    | 2    | 4    | 6    | 8    | 10   | 12   | 14   |
| 1 recommended dose | 0    | 0.3  | 1.3  | 1.6  | 2.3  | 3.3  | 5    | 5    | 5    |
Table 6. Number of germinating crabgrass leaves after spraying quinclorac.

| Dose                  | Days |
|-----------------------|------|
| 1 recommended dose    |      |
| 2 times               |      |
| 3 times               |      |
| 17                    | 0.6  |
| 19                    | 1    |
| 21                    | 1.3  |
| 23                    | 1.6  |
| 25                    | 2    |
| 27                    | 2    |
| 29                    | 0    |

According to table 6, from the spraying of 3 times the standard concentration of quinclorac on Nov. 16 to the end of observation on Dec. 17, there was no young shoot germinated in the experimental area, which meant that crabgrass was completely killed and no new leaves germinated. This also proves that the efficacy of quinclorac is the best when it is used at 3 times the standard concentration. No leaf died since Dec. 11 and began to germinate new leaves in the test area at using the standard concentration of quinclorac one time. The test area with 2-fold standard concentration was later; new leaves germinating were observed for the first time on Dec. 13. Moreover, compared with the pharmacodynamic curves of metsulfuron-methyl and flazasulfuron, the controlling effect of quinclorac is still the best of the three.

3.4. Discussion

Echinochloa crus-galli L. is a major weed in rice fields in China, and quinclorac has been long used for its control [7]. Quinclorac was double effectiveness than metsulfuron-methyl to control crabgrass. Flazasulfuron also better than metsulfuron-methyl, but less than quinclorac. The optimum period of efficacy of these three herbicides was within 12 days after spraying. After that, the number of dead shoots of crabgrass showed a steady decline. Among them, the number of new leaf germinated after metsulfuron-methyl was nearly twice as much as that in the experimental area of quinclorac. By observing the turf biomass in the experimental area, it was also found that the efficacy of metsulfuron-methyl was worse than that of flazasulfuron and quinclorac, that is to say, the comprehensive efficacy of metsulfuron-methyl was worse than that of flazasulfuron and quinclorac. On the contrary, the number of shoots killed by quinclorac in the first 12 days was the highest, and the number of leaf regeneration in the later period was the lowest, and the comprehensive effect was the best.

Large crabgrass is a major grass weed widely distributed across China. Yu [8] collected 26 large crabgrass populations from maize field, found out 25 populations resistant to nicosulfuron. Li [9] reported that field applications of nicosulfuron have been ineffective in controlling crabgrass populations in Shandong Province, China and then found out Trp574Arg substitution was the main reason for crabgrass resistance to ALS-inhibiting herbicides. Zhu [10] summarized 30 weed species that have evolved resistance to 11 herbicide sites of action in recent years in China, in which crabgrass can resist to the nicosulfuron, quiralofop-ethyl, and Sethoxym. However, metsulfuron-methyl and flazasulfuron are similar with nicosulfuron, which are same kind of sulfonyurea systemic herbicides, maybe that is the one of reasons metsulfuron-methyl are weak to control crabgrass in this experiment.

4. Conclusion

In this experiment, quinclorac are better efficacy than metsulfuron-methyl and flazasulfuron. The efficacy of quinclorac at recommended dose is 2.2 times higher than that of metsulfuron-methyl, and 1.3 times higher at three times recommended dose. Using quinclorac is the better option when crabgrass have over 2 tillers.

In the study of weed survey [11,12], crabgrass was found to be one of the most abundant malignant weeds in landscape. For a golf course, chemical weed control of crabgrass is undoubtedly the best choice at present. Brian [13] pointed out there are no POST herbicides are registered for crabgrass control, because of high turfgrass injury and little residual control, there are not an effective substitute for using
pre-emergence herbicides for southern crabgrass control. So, for crabgrass controlling, using pre-emergence herbicides are better than post-emergence herbicides. This strategy allows for the reduction of the number of herbicide applications, reducing costs and the environmental impact of pesticides [14].

References
[1] Sun J X 2008 Grass Science 3rd ed. (China Agricultural Publishing House, Beijing China)
[2] Turner F A, Van A and Rene C 2013 In situ emergence timing of large and small crabgrass in residential turfgrass of Southern Ontario Can. J. Plant Sci. 93 503-9
[3] Johnso B J 1994 Tank-mixed herbicides on Large crabgrass (digitaria-sanguinalis) and goosegrass (eleusine-indic) control in common bermudagrass (cynodon-dactylon) Turf Weed Sci. 42 216-21
[4] Smith A E 1994 Influence of norflurazon induced chlorosis on bermudagrass (cynodon-dactylon) hay production Weed Technol. 8 508-11
[5] Jeffrey F D 2002 Detection of fenoxaprop resistant smooth crabgrass (digitaria ischaemum) in Turf Weed Technol. 16 396-400
[6] Neil D, Mack S C and Fuqua R W 2015 Phase-change lines, scale breaks, and trend lines using excel 2013 J. Appl. Behav. Anal. 48 478-93
[7] Peng Q, Han H P, Yang X et al 2019 Quinclorac resistance in echinochloa crus-galli from China Rice Sci. Online First Article available http://www.ricescience.org/EN/abstract/abstract9823.shtml
[8] Yu M, Si C and Liu M J et al 2017 Investigation of resistance levels and mechanisms to nicosulfuron conferred by non-target-sitemechanisms in large crabgrass (Digitaria sanguinalis L.) from China Pestic. Biochem. Phys. 141 84-9
[9] Li J, Li M and Gao X X et al 2017 A novel amino acid substitution Trp574Arg in acetolactate synthase (ALS) confers broad resistance to ALS-inhibiting herbicides in crabgrass (digitaria sanguinalis) Pest Manag. Sci. 73 38-43
[10] Zhu J W, Wang J and DiTommaso A et al 2018 Weed research status, challenges, and opportunities in China Crop Prot.
[11] Saha D, Marble S C and Pearson B J et al 2019 Mulch type and depth, herbicide formulation, and post application irrigation volume influence on control of common landscape weed species Horttechnology 29 65-77
[12] Parker E T, McElroy J S and Flessner M L 2015 Smooth crabgrass and goosegrass control with metamifop in creeping bentgrass Horttechnology 25 757-61
[13] Brian D G, Barry J B and Unruh J B et al 2015 Evaluation of alternative herbicides for southern crabgrass (digitaria ciliaris) in St. Augustine grass Weed Technol. 29 536-43
[14] Agostinetto D, Fontana L C, Vargas L, Perboni L T, Polidoro E and Silva B M 2014 Competition periods of crabgrass with rice and soybean crops Planta Daninha 32 31-8