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Published version:

DOI:10.1016/j.cropro.2012.03.005

(Article begins on next page)

The effects of water management, timing and the rate of several herbicides on the growth of *Murdannia keisak* (Hassk.) Handel-Mazz

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Abstract

Murdannia keisak is a competitive rice weed found throughout the world. The aims of this study were to investigate the influence of different water managements on the growth *of M. keisak* under greenhouse conditions, and to assess the efficacy of common rice herbicides against it under field conditions.

Three water management techniques were tested under greenhouse conditions: saturation, intermittent irrigation, and continuous flooding. The efficacy against *M. keisak* was evaluated in paddy fields during 2003-2005. In 2003, bispyribac-sodium was applied alone or in combination with triclopyr or metosulam at 20, 27, and 32 days after seeding (DAS). In 2004 and 2005, bispyribac-sodium was applied once (30 DAS), but at two application rates.

Results for the three water treatments showed continuous flooding reduced *M. keisak* biomass most as confirmed by aboveground fresh weights. In the paddy field experiments, bispyribac-sodium also proved highly effective against *M. keisak* and was selective to rice with more than 90% efficacy. The addition of tryclopyr or metosulam to bispyribac-sodium

failed to improve its herbicidal efficacy. Finally, the best *M. keisak* control at field condition was obtained with continuous flooding combined with bispyribac-sodium.

Key words

Rice, bispyribac-sodium, marsh dayflower, water management.

1. Introduction

Murdannia genus belongs to the spiderwort (Commelinaceae) family and includes several weed species of particular concern in rice fields. *Murdannia* species are native to eastern Asia where they grow in both cultivated and natural areas (Baki, 1997) while *Murdannia nudiflora* (L.) Brenan (Bastidas López, 1996; Plaza, 19983; Rojas, 2002; Wilson, 1981) is a common rice weed in Latin America. *Murdannia keisak* (Hassk.) Handel-Mazz., also known as *Aneilema keisak* or by the common name Marsh dayflower, has been reported as a weed in South Carolina cultivated rice paddies (Swearingen, 2002), and has become established and naturalised in other cultivated or natural areas (Dunn, 1990) of the USA. In Italy *M. keisak* was first found in 1974 (Pignatti, 1982) in spontaneous vegetation; significant rice field infestations have only been reported since the late ‘90s (Berti, 2006; Tesio, 2004).

The ability of this plant to out-compete native vegetation is mainly caused by its fast growth and its development of a dense canopy mat (King, 2000; Rundell, 1999). According to Dunn and Sharitz (1991), the flexibility of *M. keisak* allows it to adapt readily to new environments. *M. keisak* is considered invasive in marshes, swamps, ditches, creek and riverbanks, and around ponds and lakes as it rapidly crowds out desired native herbaceous vegetation by forming dense floating pads. Even in its native areas, this species is a difficult paddy field weed as it grows rapidly in shade rather than in full sun (Dunn, 1990).

M. keisak presents alternating linear or lance-shaped leaves of about 6 cm long and 1 cm wide. Each leaf base has a closed tubular and hairy sheath. The stems are succulent, root at the nodes and grow prostrate. Flowering generally occurs in September-October. The flowers, solitary or in groups of 2-4 axillary racemes, usually develop at the stem ends or from the leaf axil; they show 3 green sepals, ovate to oblong, and 3 pink petals that are a little longer than the sepals. The stamens are 6 (only 2 or 3 fertile) and the ovary is superior. The fruits are 6-7 mm long smooth capsules, ellipsoid to oval in shape, pointed at the tip, and contain about 48 grey and flat seeds (Pignatti, 1982). Reproduction occurs by fragmentation and seed production. Temperatures of less than 8 °C, together with seed burial depth and submersion, depress seedling emergence (Sago, 1996).

Even though *M. keisak* is of concern in several regions of the world, its eco-biology, agronomic management, and herbicide sensitivity remain sketchy. Useful information on the effects of different rice cropping and water management practices on its emergence, growth, competitiveness, seed production and dispersal is absent in the literature. Some reports indicate that species of the genus *Murdannia* are successfully controlled by several herbicides: bispyribac-sodium (JinHao, 2000; HuiLi, 2002), bentazone, as well as mixtures containing bentazone (Kitano, 1999), cloroacetamides (mefenacet, pretilachlor), molinate, MCPA (Sago, 1996) and 2,4-D (Wilson, 1981). However, the effects of water management on *M. keisak* must be better understood as they are fundamental to defining an integrated strategy for control of a species so highly related to its aquatic environment.

The aims of this study were: (1) to evaluate the effects on *M. keisak* of different water management conditions in the greenhouse, and (2) to investigate the sensitivity of the species to widely used rice herbicides under field conditions.

2. Materials and methods

The greenhouse experiments were performed during 2002 at the faculty of Agriculture of the University of Torino (Grugliasco, Italy). Field experiments were conducted during the 2003, 2004, and 2005 growing seasons in the Vercelli area (NW Italy), one of the most important areas for rice cultivation in Italy.

2.1. Greenhouse experiments

During the 2001 growing season, seeds of *Murdannia keisak* were collected from plants grown in naturally infested paddy fields of Northern Italy and multiplied in the greenhouse. Seeds harvested from these greenhouse-developed plants were air dried in open trays at room temperature for 30 days, and then cooled in deionized water at 4 °C for a minimum of two months.

The greenhouse was equipped with a shade tissue positioned outside of the structure to avoid excessive temperatures and to result in 47% light reduction. Natural light filtered through the shade tissue and was supplemented with metal-halide lamps, to obtain a total radiation of about 55 µmol s^{-1} m^{-2}. The average maximum, minimum, and mean temperature values experienced were 30.3 °C, 19.3 °C, and 24.3 °C while the average maximum, minimum, and mean relative humidity values were 85.2%, 35.8%, and 62.3%, respectively.

Seeds of *M. keisak* and rice (*Oryza sativa* L.) cv. Selenio (medium grain *japonica*-type variety) were placed in germination trays and maintained at 25 °C until the root tip of both species had erupted and extended from the seed coat 2-3 mm. Germinated seedlings were transplanted into 100 cm^2 pots (9 seeds per pot) filled with water-saturated commercial potting media. After seeding, a 3x2 factorial design was applied to both *M. keisak* and rice.

The first factor, represented by water management, had three levels: saturation (SA), intermittent irrigation (II), and continuous flooding (CF). SA treatment was performed by placing the pots in trays with a 5 cm water layer and letting the soil be saturated through the holes in the base of the pot. For treatment II, irrigation took place only when the rice began to show signs of drought stress (beginning of leaf folding) and was conducted by immerging the pots until soil saturation. In treatment CF, the soil was continuously flooded through maintenance of a 10 cm water layer above the pot.

The second factor, watering timing, referred to when the differing water management strategies (SA, II, and CF) occurred. Two different timeframes were used — immediately after seeding ("Early"), or ten days thereafter ("Late"). To avoid plant damage during the first ten days of treatment combination CF X Late, pots were maintained in trays containing a minimal water layer.

All the treatments were arranged according to a randomized complete block design structure with six replicates; each pot served as an experimental unit. Pots of both species were fertilized at about two weeks after seeding by replacing the water in the trays with solution containing 0.25 g L^{-1} of N-P-K fertilizer (10-16-25). At approximately 50 days after seeding, the aboveground fresh weight of each pot of *M. keisak* and rice was measured.

A two-factor analysis of variance was conducted on the fresh weight data in which *M. keisak* and rice responses were treated separately.

2.2. Field experiments

Field experiments were conducted during 2003-2005 in a paddy field highly infested by *M. keisak*. The paddy field was seeded with 180 kg ha^{-1} of the cultivar Loto (long grain *japonica*-type variety) at the end of May. Control of *Heteranthera* spp., another weed in the field, was achieved by applying oxadiazon at 270 g a.i. ha^{-1}. The field was drained at least two days prior to oxadiazon treatment, submerged two days after being sprayed, and then kept flooded for the duration of the study. Continuous submersion was the adopted water management in the field experiments because this solution resulted to be the most effective for the control of *M. keisak* in the greenhouse experiments.

The field experiments included herbicides which in a previous work proved to be effective against *M. keisak* under greenhouse conditions (Tesio et al.,2004).

The 2003 trial included four treatment combinations (Table 1): 1) bispyribac-sodium combined with the anionic adjuvant Biopower (sodium salt of alchilether sulfate, Bayer CropScience), 2) bispyribac-sodium combined with triclopyr or 3) metosulam and Biopower, and 4) a mixture of propanil combined with triclopyr and Trend (ethoxylated tridecyl alcohol, DuPont). Bispyribac-sodium was chosen because it performed best in the greenhouse experiment. The bispyribac-sodium-based treatments were applied at 20, 27, or 32 days after seeding (DAS) to coincide with the rice at BBCH stage 12-13, 13-21, or 15-23, and *M. keisak* at stage 11-13, 12-15, or 15-18, respectively. We applied the mixture of propanil, triclopyr, and Trend twice, at 27 and 32 DAS.

The 2004 and 2005 experiments included treatments based on bispyribac-sodium applied at the rate tested in the previous experiments and at a 20% reduced rate when combined with wetting agents Biopower and Dash (methyl palmitate 172.5 g l^{-1}). In both years, the herbicides were applied only once—at 30 DAS—when the rice was at BBCH stage 13-21 and *M. keisak* was at 12-15.

All field experiments were laid out in a completely randomized design with four replicates and elementary plots of 24.75 m^2. The efficacy of the various herbicidal combinations on *M. keisak,* as well as their selectivity to rice, were evaluated according to EPPO/OEPP n. 62 guidelines by scoring the results against a range from 0 (no efficacy against weed; no phytotoxicity to crop) to 100 (complete control of weed; crop destroyed). We conducted efficacy assessments throughout the growing seasons: at 10, 20, 40, and 80 days after treatment (DAT) in 2003, and at 7, 14, and 30 DAT in 2004 and 2005.

The analysis of variance was performed on the efficacy and phytotoxicity data with the means separated using the LSD post-hoc test ($P < 0.05$).

3. Results

3.1. Greenhouse experiments

Water management significantly affected the growth of *M. keisak* and rice plants. Pots maintained in saturated conditions (SA) resulted in the greatest aboveground fresh weights, both in *M. keisak* and rice plants. On the other hand, the lowest fresh weights were recorded for *M. keisak* plants kept continuously flooded (CF) and for rice plants intermittently irrigated (II). CF values for the weed and rice were reduced when compared to their counterpart plants under SA treatment (Figure 1).

A significant interaction between water management and application timing was also found for both the weed and the rice plants. In fact, late application of the various water strategies always yielded higher aboveground fresh weights except in one instance: *M. keisak* grown in saturated conditions (Figure 1).

3.2. Field experiments

In the 2003 experiment, bispyribac-sodium showed effectiveness against *M. keisak* and sufficient selectivity to rice plants in all water treatments (Table 2). Furthermore, all treatments that included bispyribac-sodium combined with the wetting agent Biopower scored an efficacy greater than 97% against *M. keisak* in assessments carried out from 20 DAT. Among the timing options, slightly better results, for both efficacy and selectivity, were obtained when bispyribac-sodium + Biopower were applied at 27 DAS. In the case of propanil mixed with triclopyr and Trend, even when doubled in strength, the efficacy score failed to exceed 94 (Table 2). Regardless of application time, the addition of metosulam or tryclopir to bispyribac-sodium did not significantly improve the control of *M. keisak*.

During 2004 – 2005 all bispyribac-sodium treatments were highly effective against *M. keisak,* showing a consistently high efficacy (> 92%) at 7 DAT (Table 3), and complete control of the weed at 14 DAT and 30 DAT. Bispyribac-sodium applied in combination with the wetting agent Biopower was less phytotoxic to rice than when combined with Dash at the 7 DAT and 14 DAT assessments.

4. Discussion and conclusions

This study investigated the effects of different water management strategies on *Murdannia keisak* as well as its sensitivity to common rice herbicides. Results indicated that the most common water management for European rice, continuous flooding, significantly affected *M. keisak* growth. Rice biomass was highest in saturated conditions while rice growth was mostly limited by intermittent irrigation. Our results were consistent with other studies (Juraimi, 2009), in which the highest values of rice plant biomass were recorded in saturated soil. Only a slight reduction in biomass was observed in continuously flooded conditions relative to saturated conditions.

At the field scale, continuous flooding of the fields is the most adopted water management strategy, as a water layer maintained at the soil surface results in reduced thermal oscillations (Ikehashi, 2007). The results of the high growth we observed in saturated soil might be explained by the favourable environmental conditions of the greenhouse, and in particular the limited variation temperature, that is quite unusual in rice field cultivation.

An increased use of intermittent irrigation or saturation instead of continuous flooding has been suggested (Chapagain, 2009;Yang, 2004) to reduce water utilization, but both practices can adversely affect rice growth and favour *M. keisak* development. Similar behaviour has been observed in *Fimbristylis littoralis* Gaud., *Ludwigia hyssopifolia* (G. Don) Exell, and *Cyperus iria* L. Yet, other rice weed species, such as *Monochoria vaginalis* (Burm.F.) Presl and *Cyperus difformis* L. have shown no effect from continuous flooding (Chauhan and Johnson, 2009). Generally, the effect of water on weeds depends on species, water layer depth, and time submersion begins (Pons, 1982;Chauhan, 2009). In field experiments bispyribac-sodium and triclopyr controlled *M. keisak* at lower rates than those recommended on the herbicide product labels.

The results of this study can lead to a strategy for successful control of this weed through optimal herbicide choice, rate, application timing and water management. In particular, our results showed that continuous flooding, coupled with half-strength bispyribac-sodium and the adjuvant Biopower applied once between the 3-leaf stage and first tiller of crop growth, controlled *M. keisak* without any remarkable negative effects to rice. Similarly, *Echinochloa crus-galli* in paddy rice is already controlled with this herbicide treatment at the same growth stage as that required for *M. keisak* control (Koger et al. 2007; Vidotto et al. 2007), which makes this strategy efficient to control both weeds in a single application.

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Figure captions

Figure 1. Aboveground fresh weight (g plant^{-1}) of *M. keisak* and rice. Water management strategies not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test). Regular and italic letters refer to *M. keisak* and rice, respectively. Error bars indicate SE (n=6).

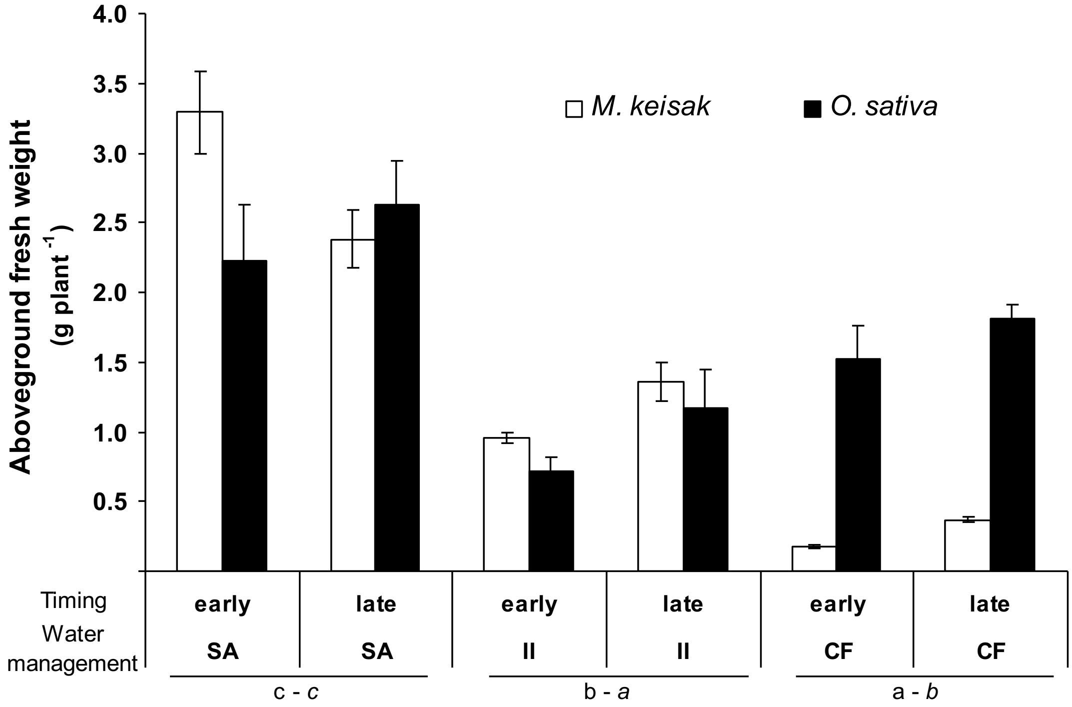

Figure 2. Aboveground fresh weight (g plant^{-1}) of *M. keisak* and rice. Water management strategies not sharing the same lower-case letter are significantly different at *P*< 0.05 (LSD test). Regular and italic letters refer to *M. keisak* and rice, respectively. Error bars indicate SE (n=6).

Table 1. Herbicides included in the field experiments, rates, and application timings.

Year	Treatment	Rates (g a.i. ha^{-1})	Application timing (DAS)[1]
2003	bispyribac-sodium + Biopower	31 + 265	20; 27, 32
	bispyribac-sodium + triclopyr + Biopower	31 + 750 + 265	20; 27, 32
	bispyribac-sodium + metosulam + Biopower	31 + 428 + 265	20; 27, 32
	propanil + triclopyr + Trend (repeated twice)	4000 + 750 + 400	27 + 32
2004 and 2005	bispyribac-sodium + Biopower	25.8 + 265	30
	bispyribac-sodium + Biopower	31 + 265	30
	bispyribac-sodium + Dash	25.8 + 800	30
	bispyribac-sodium + Dash	31 + 800	30

[1] *DAS= Days After Seeding*

Table 2. Efficacy against *Murdannia keisak* and phytotoxicity on rice of herbicides applied in the 2003 field experiment. Letters refer to significance among treatments, according to the LSD test. Comparisons are made among values of a same column, thus within each assessment (DAT) for either efficacy or phytotoxicity.

Treatment	Efficacy[1]				Phytotoxicity[1]			
	10 DAT	20 DAT	40 DAT	80 DAT	10 DAT	20 DAT	40 DAT	80 DAT
bispyribac-sodium + Biopower (20 DAS)	96.3ab	100.0a	99.5a	98.8ab	10.0bc	5.0abc	2.5bc	1.3b
bispyribac-sodium + Biopower + metosulam (20 DAS)	97.3a	98.5a	99.0a	99.0ab	8.8bcd	3.8bcd	8.8a	1.3b
bispyribac-sodium + Biopower + triclopyr (20 DAS)	98.0a	99.5a	99.5a	99.5a	15.0a	8.8a	2.5bc	1.3b
bispyribac-sodium + Biopower (27 DAS)	98.3a	100.0a	100.0a	100.0a	6.3cde	1.3cd	0.0c	0.0b
bispyribac-sodium + Biopower + metosulam (27 DAS)	99.5a	100.0a	100.0a	100.0a	7.5bcde	1.3cd	1.3c	0.0b
bispyribac-sodium + Biopower + triclopyr (27 DAS)	98.3a	99.5a	99.5a	99.5a	8.8bcd	5.0abc	2.5bc	1.3b
bispyribac-sodium + Biopower (32 DAS)	95.8ab	97.8ab	97.5a	98.8ab	3.8ef	1.3cd	0.0c	0.0b
bispyribac-sodium + Biopower + metosulam (32 DAS)	97.5a	98.3a	100.0a	100.0a	6.3cde	2.5bcd	2.5bc	1.3b
bispyribac-sodium + Biopower + triclopyr (32 DAS)	97.0a	98.0ab	98.8a	98.8ab	5.0de	5.0abc	5.0b	5.0a
propanil + triclopyr + Biopower (27 DAS and 32 DAS	87.5b	91.3b	93.8a	92.5b	7.5bcde	2.5bcd	2.5bc	2.5ab

[1]: efficacy and phitotoxicity expressed as visual score. 0: no efficacy against the weed, no phytotoxicity towards crop; 100: complete control of weed, crop destroyed.

Table 3. Efficacy against *Murdannia keisak* and phytotoxicity on rice of bispyribac-sodium applied in 2004-2005 field experiments. Letters refer to significance among treatments, according to the LSD test. Comparisons are made among values of a same column, thus within each assessment (DAT) for either efficacy of phytotoxicity.

Treatment	Efficacy[1]			Phytotoxicity[1]		
	7 DAT	14 DAT	30 DAT	7 DAT	14 DAT	30 DAT
bispyribac-sodium 25.8 g a.i. ha^{-1} + Biopower	92.5a	100.0a	100.0a	0.5c	0.5c	0.0
bispyribac-sodium 31 g a.i. ha^{-1} + Biopower	93.8a	100.0a	100.0a	2.5b	2.5b	0.0
bispyribac-sodium 25.8 g a.i. ha^{-1} + Dash	92.5a	100.0a	100.0a	2.5b	2.5b	0.0
bispyribac-sodium 31 g a.i. ha^{-1} + Dash	95.0a	100.0a	100.0a	4.0a	4.0a	0.0

[1]: efficacy and phitotoxicity expressed as visual score. 0: no efficacy against the weed, no phytotoxicity towards crop; 100: complete control of weed, crop destroyed.