

Article

Efficacy of Selected Herbicides and Straw Mulch for the Management of Six Invasive Alien Plants

Sima Sohrabi ^{1,*}, Javid Gherekhloo ^{2,*}, Antonia M. Rojano-Delgado ³, Hadi Nekahi ², Mohammad Taheri ², Rafael De Prado ⁴ and José Ramón Arévalo ⁵

¹ Rice Research Institute of Iran (RRII), Rasht 41996-13475, Iran

² Department of Agronomy, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan 49138-15739, Iran

³ Department of Agricultural Chemistry, Soil Science and Microbiology, University of Córdoba, 14014 Córdoba, Spain; q92rodea@uco.es

⁴ Agroforestry and Plant Biochemistry, Proteomics and Systems Biology, Department of Biochemistry and Molecular Biology, University of Córdoba, 14014 Córdoba, Spain

⁵ Department of Botany, Ecology and Plant Physiology, University of La Laguna, 38206 La Laguna, Spain

* Correspondence: simsoh@gmail.com or s.sohrabi@areeo.ac.ir (S.S.); gherekhloo@gau.ac.ir (J.G.)

Abstract

Managing invasive alien species (IAS) is a major challenge for conserving ecosystems because of their deleterious impacts. This study evaluated the efficacy of five selective herbicides and wheat straw mulch against six invasive alien plant (IAP) species in Iran. Field observations from 2021 to 2025 showed that these species are concentrated in agricultural regions, particularly in summer crops in northern Iran. Five available herbicides (pendimethalin 3 lit h⁻¹, imazethapyr 0.75 lit h⁻¹, nicosulfuron 2 lit h⁻¹, bentazone 2 lit h⁻¹, and 2,4-D+MCPA 1.5 lit h⁻¹) and wheat straw mulch (2 tons ha⁻¹) were used to reduce the growth of six IAP species during summer 2025. Pendimethalin (as a pre-emergence herbicide) was effective (>90%) against all species apart from *Ipomoea hederacea* (≈60%). While 2,4-D+MCPA (as a post-emergence herbicide) effectively controlled five species, bentazone was effective only against *Sida rhombifolia* and *I. hederacea*. Nicosulfuron showed high efficacy (80%) only against *I. hederacea*. Straw mulch was more effective against *Euphorbia nutans* but was not effective properly against *Ipomoea* species. The efficacy of mulch and some herbicides depended on species identity, even within the same genera (*Ipomoea* and *Euphorbia*). Our results can help in the successful management of these invasive plants in northern Iran to minimize their impact on yield and quality of crops. As IAPs in environmental areas, this result will also be advantageous.

Keywords: invasive alien plants (IAP); agriculture; straw mulch; integrated management



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1. Introduction

Invasive plants have been identified worldwide as a primary threat to both native biodiversity and ecosystem functioning [1–4]. Food production is at risk because numerous invasive plants have emerged as weeds in agricultural areas [5,6]. In response to these challenges, many nations have developed legal frameworks to prevent, identify, eradicate, and control invasive alien plant species [7]. Land managers have several options for controlling invasive alien plants, including chemical (herbicides), mechanical (e.g., pulling, mowing, and tilling), physical (e.g., mulching), and biological (e.g., using herbivores) treatments. Choosing an appropriate control method is challenging because managers must consider

key biological and ecological aspects of the target species, predict treatment efficacy, anticipate potential adverse effects on non-target organisms, and account for technical and economic feasibility [8]. Herbicides are frequently used to control invasive alien plants in natural ecosystems, although they were first developed to control unwanted weeds in agricultural systems [9]. Herbicides offer several advantages over other management approaches: they can rapidly eliminate invasive alien species, require minimal human effort, are often cost-effective, and do not directly disrupt soil structure [9]. Mulching is a physical method for weed suppression in cultivation. It is defined as the placement or application of any material in a thick layer, coating, or protective covering on the soil surface [10]. The main factors contributing to weed suppression include light exclusion, reduced temperature and air availability for germinating weed seeds, leaching of allelochemicals, and the creation of a physical barrier [11]. Since small seeds require light for germination, the impact of mulch on various seed sizes is more prominent [12–14].

To achieve maximum control efficiency and prevent the spread of invasive alien plants into new areas, a multifaceted management approach is recommended. Consideration of alternatives such as mulching, tillage, and biological control is essential for integrated weed management strategies (IWM) [15].

Iran is situated at the crossroads of Central Asia, South Asia, and the Arab states of the Middle East. This location provides a suitable pathway for the introduction of alien plants through human activities, both intentional and unintentional. The most recent survey of alien plants in Iran reported more than 310 species, most of which were introduced by human activities, and the rate of new introductions is continuing due to a lack of a robust quarantine system [16]. A large proportion of these species are problematic in agricultural areas. Many croplands are infested by these species, which compete with crops, reduce yields, increase labor requirements, and ultimately increase food costs for consumers. Their negative environmental and socioeconomic impacts have highlighted the high management priority of many alien plant species in Iran [17]. Information on current distribution, the efficacy of available management options, and potential management practices is critical for land management and biodiversity conservation to minimize their negative impacts [18]. Recent studies in Iran have highlighted the greater proportion and faster spread of alien plants in northern Iran (Figure 1).

Despite concerns regarding IAS in agriculture and environmental sectors, there is a lack of national management lists and appropriate strategies for IAS in Iran, making it an increasingly prevalent issue. The detrimental impact of the IAS, rapid spread, and the interference with achieving optimal crop yields were prioritized for evaluating various management strategies for six invasive alien species in Iran (Table 1). Some species such as *Euphorbia nutans* and *Sida rhombifolia* have wider distributions across the three northern provinces of Iran. Because *S. rhombifolia* has been detected in Mazandaran and Guilan provinces, the main rice-producing areas of Iran, there is a risk of invasion into rice fields, especially as rice production shifts from flooded to aerobic systems. This species is mentioned as a weed problem in rice [19–22]. *Ipomoeas* and *Euphorbia* species are reported as problematic weeds in maize, beans, cotton, soybean and orange plantations in Greece, Iran, Turkey and Spain [23–25]. Herbicide resistance is another significant concern related to these species, as numerous records indicated their capacity to develop resistance [26–28].

Identifying efficient management options will reduce the likelihood of further establishment in other areas and minimize their impacts on agriculture and biodiversity.

Considering these challenges, this study focuses on invasive alien plants (IAPs) and aims to provide insights for broader IAS management strategies in the country for the first time. We hypothesized that (i) available herbicides in Iran would significantly improve the control of studied AIPs, (ii) the efficiency of applied herbicides would depend on species

type, (iii) mulch would significantly reduce the establishment of some invasive alien plants due to their different seed size, and (iv) additional management guidance would improve management prospects for these species.

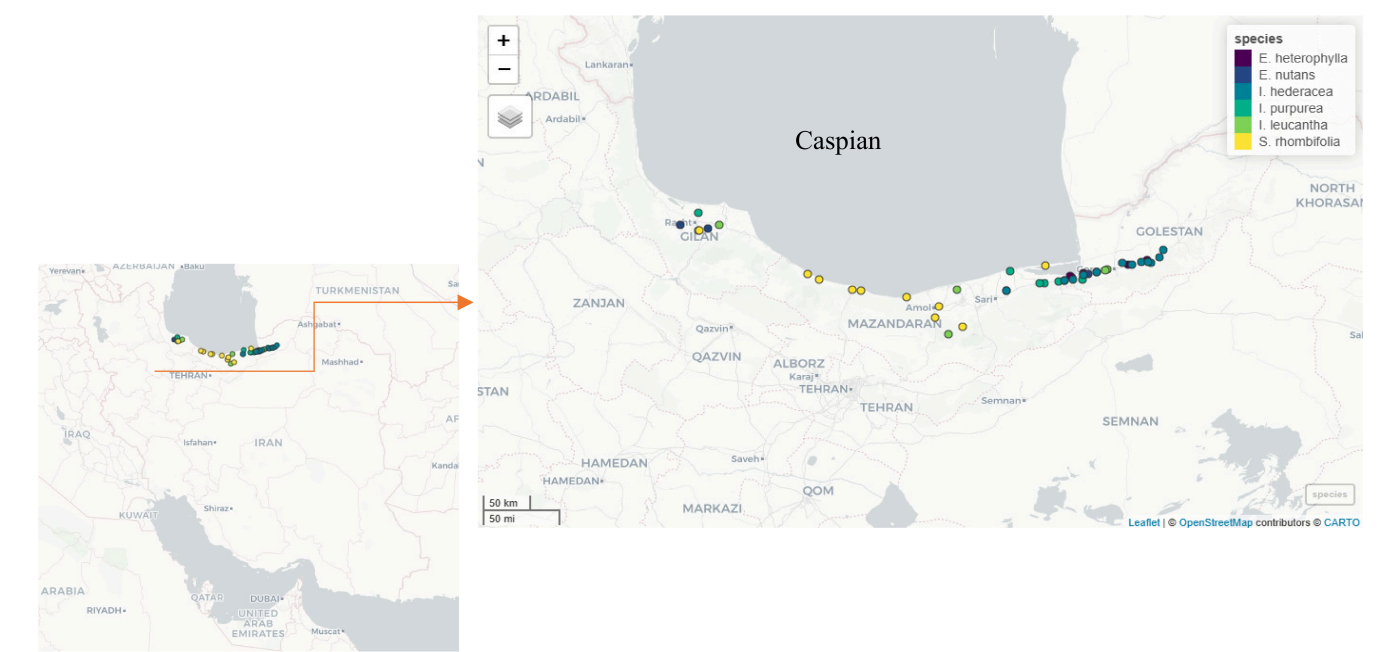


Figure 1. Current distribution of the six alien weeds in northern Iran based on field observation from 2021 to 2025 and published data from 2003 to 2026.

Table 1. Alien weeds studied in this study and their main characteristics.

Invasive Alien Plant	Common Name	Origin	Seed Collection Area	Infested Croplands	Seed Dormancy Breaking
<i>Euphorbia heterophylla</i> L.	Painted euphorbia	Tropical and subtropical America	Golestan, Kordkuy	Soybean	After ripening (6 months)
<i>Euphorbia nutans</i> Lag.	Nodding spurge	Southeastern Canada to northern Venezuela and the Caribbean	Golestan, Kordkuy	Soybean, cotton	After ripening (6 months)
<i>Ipomoea purpurea</i> (L.) Roth	Tall morning-glory	Tropical and subtropical America	Golestan, Gorgan	Citrus plantations	H2SO4 (5 min)
<i>Ipomoea</i> × <i>leucantha</i> Jacq.	Whitestar morning-glory	Central and southeastern USA	Golestan, Kordkuy	Soybean, cotton	H2SO4 (20 min)
<i>Ipomoea hederacea</i> Jacq.	Ivy-leaved morning glory	Mexico	Golestan, Kordkuy	Soybean, cotton, maize	H2SO4 (5 min)
<i>Sida rhombifolia</i> L.	Arrowleaf sida	Tropical and subtropical Old World	Mazandaran, Babol	Field margins	H2SO4 (120 min)

2. Materials and Methods

2.1. Plant Material

Based on field observations from 2021 to 2025 and published data [29–31], six alien weeds were selected to assess management options (Table 1). Seeds were collected from infested areas in Golestan, Mazandaran, and Guilan provinces during summer 2024. Before the main experiment, a germination test was conducted to determine the germination percentage of each species. Because the seeds had high dormancy, which may prevent germination uniformity, dormancy-breaking treatments were applied according to the

dormancy type of each species (Table 1). *Ipomoea* species and *Sida rhombifolia* have hard seed coats; therefore, H₂SO₄ was used to break dormancy [32,33]. *Euphorbia nutans* and *E. heterophylla* seeds did not germinate immediately after ripening but germinated after 6 months at room temperature. Non-dormant seeds were then planted in pots (30 cm diameter × 30 cm height). Each pot served as an individual experimental unit, allowing precise monitoring and data collection. The experiment was conducted using a factorial arrangement in a completely randomized design (CRD), with three replications for both herbicide and mulch treatments. In total, 108 pots were used in this study, including herbicide and mulch treatments (six cases), plant species (six cases), and replications. The soil (clay loam) was collected from agricultural soil at the Agronomic Research Field, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. To ensure appropriate representation of the field population, seedlings at the two- to three-leaf stage were randomly thinned to a maximum of 10 individual seedlings for *Ipomoea* species and 15 seedlings for *Sida* and *Euphorbia* species. The climatic conditions for both applications were similar, with temperatures between 25.0 and 34.5 °C, an average relative air humidity of 62% and moist soil.

2.2. Herbicide Application

Experiments were carried out in the summer of 2025 in a greenhouse under natural conditions. Plants were sprayed when they reached about 4–5 leaves stage (16 June 2025). Plants were treated with five different herbicides at the recommended field rates specified in Table 2, using a sprayer delivering 300 L ha^{−1} and equipped with a flat-fan 8001E nozzle (TeeJet®, Spraying Systems Co., Wheaton, IL, USA) and a constant pressure of 2.0 kgf cm^{−2}, positioned 0.50 m from the targets. The pots were exposed to a spray application utilizing the calibrated spraying apparatus. The untreated control pots were not sprayed with herbicides. All experiments were arranged in a fully randomized factorial design, with three replicates for each treatment. Shoot fresh and dry weights were recorded 21 days after treatment (DAT). The biometric evaluation was done in each pot to characterize the efficiency of the treatment. Seedling number, shoot height (cm), and shoot fresh and dry weights (g) in each pot were recorded 21 days after treatment. The length of seedlings per pot was measured using a linear scale from stem base to stem tip.

Table 2. Characteristics of the herbicides used for control of the six alien weeds.

Common Name of Herbicide (Brand Name)	Formulation	Rate ha ^{−1}	Mechanism of Action	Application Time
Pendimethalin (Prowl)	CS 45.5%	3 L	Disruption of mitosis	Pre-emergence
Imazethapyr (Persuit)	SL 10%	0.75 L	Inhibits acetolactate synthase (ALS)	Post-emergence
Nicosulfuron (Cruz)	OD 4%	2 L	Inhibits acetolactate synthase (ALS)	Post-emergence
Bentazone	SL 48%	2 L	Inhibits photosystem II	Post-emergence
2,4-D+MCPA	SL 67.5%	1.5 L	Synthetic auxin	Post-emergence

Weed control efficiency (WCE) measured the reduction in weed dry weight in a treated pot relative to weed dry weight in the untreated control. It is expressed as a percentage, where WC is the weed dry weight in the control (untreated) pot and WT is the weed dry weight in the treated pot (Equation (1)) [34].

WCE = [(WC − WT)/WC] × 100 (1)

2.3. Use of Wheat Straw as Mulch

To evaluate the influence of wheat straw on the emergence of alien weeds, 10 seeds for species with large seeds (the three *Ipomoea* species), 15 seeds for species with smaller seeds (*E. heterophylla* and *S. rhombifolia*), and 20 seeds for *E. nutans* were placed on the soil surface in 14 cm-diameter pots with three replications. The pots were then mulched with wheat straw at a residue volume equivalent to 2 tons ha⁻¹. Pots without straw mulch but containing weed seeds were used as controls. Before placement in pots, residues were chopped into smaller pieces (approximately 5 cm) and dried in an oven at 70 °C for 72 h. Temperature, soil, and water conditions were similar to those described for the herbicide experiment. Seedling emergence was determined during the 3 weeks after planting based on visible seedlings on the soil surface. Seedling number, shoot height, and shoot fresh and dry weights in each pot were recorded 21 days after treatment (DAT).

2.4. Statistical Analyses

Weed control efficiency (WCE), mean seedling height (cm per pot), and fresh and dry biomass (g per plant) were subjected to analysis of variance (ANOVA) as a parametric test ($p < 0.05$). Data were normalized by log transformation for plant height, fresh weight, and dry weight, and by sqrt transformation for WCE, followed by subsequent analytical procedures. All parameters were subjected to ANOVA using the `lm()` function, and mean values were subsequently compared using standard deviation values. The dependent variables were the measured traits, and the independent variables were species and management options. The `agricolae` (version 1.3-7) and `ggplot2` (version 4.0.3) packages in R (version 4.5.2) were used for data analysis and visualization. Means were separated with Fisher's protected least-significant difference (LSD) test at the significance level $\alpha = 0.05$ ($p \leq 0.05$) as a post hoc test for measured values using the `doebioresearch` package (version 0.1.0). Because the interaction between the two factors was significant (Supplementary Tables S1–S4), differences between interaction levels (management $\times$ alien weeds) were tested.

3. Results

3.1. Herbicide Application

The response of invasive alien weeds based on WCE to herbicide application differed according to herbicide type, ranging from 10% to 100%. Significant differences were found for weed control efficiency (WCE) among the six species ($F_5 = 3.426$, $p < 0.05$), plant height ($F_6 = 16.126$, $p < 0.05$), fresh weight ($F_6 = 36.16$, $p < 0.05$), and dry weight ($F_6 = 35.17$, $p < 0.05$). In addition, the interaction between the two factors was significant (Supplementary Tables S1–S4). According to the mean difference test (LSD test), management options differed significantly among species, even within the same genus (Table 3). The WCE of herbicide 2,4-D+MCPA reached 100% for four species, while it was 80% for *E. nutans* and significantly lower for *S. rhombifolia* (nearly 50%). Pendimethalin demonstrated significant efficacy across all species, achieving a weed control efficacy (WCE) exceeding 90%, with the exception of *I. hederacea*, which exhibited a WCE of approximately 60%. The efficacy of bentazone and imazethapyr varied among species, but both herbicides showed greater efficacy for *S. rhombifolia* control, with 100% and 75% respectively (Figure 2, Table 3). In general, nicosulfuron was less effective than the other herbicides, although its efficacy against *I. hederacea* was approximately 80%. The efficiency of nicosulfuron for *E. nutans* was lower than other species ($\approx 10\%$). According to Figure 3, significant differences among herbicides were observed for seedling height, fresh weight, and dry weight in the two *Euphorbia* species. These traits also differed significantly among treatments in the three *Ipomoea* species (Figures 3–5). Mean comparisons for WCE revealed significant differences among management treatments for all species except *E. heterophylla*. In this species, 2,4-

D+MCPA and pendimethalin showed greater promise with 100 and 80% control efficiency, although they did not differ significantly from the other treatments (Table 3).

Table 3. Mean comparisons of measured values (transformed data) based on the LSD test at the 5% level.

Weed Species	Management	Mean Plant Height (cm)	Fresh Weight (g/Plant)	Dry Weight (g/Plant)	WCE%
<i>E. heterophylla</i>	2,4-D+MCPA	0 c	0 c	0 b	10 a
	Pendimethalin	2.23 b	0.46 bc	0.102 b	9.46 a
	Nicosulfuron	3.766 a	1.67 ab	0.442 ab	6.46 a
	Bentazone	3.633 a	1.56 ab	0.433 ab	6.33 a
	Imazethapyr	3.633 a	1.56 ab	0.409 ab	6.3 a
	Straw mulch	3.33 a	1.4 ab	0.47 ab	5.60 a
	Control	4.10 a	2.27 a	0.72 a	-
<i>E. nutans</i>	2,4-D+MCPA	2.73 c	0.26 c	0.26 c	9.20 a
	Pendimethalin	0 d	0 d	0 d	10.00 a
	Nicosulfuron	3.76 a	1.10 a	1.10 a	3.16 c
	Bentazone	3.83 a	1.03 a	1.03 a	5.56 b
	Imazethapyr	3.43 b	0.74 b	0.74 b	7.20 b
	Straw mulch	0 d	0 d	0 d	10.00 a
	Control	3.93 a	1.16 a	1.16 a	-
<i>I. purpurea</i>	2,4-D+MCPA	0 e	0 e	0 c	10 a
	Pendimethalin	2.16 d	0.59 d	0.107 c	9.76 a
	Nicosulfuron	3.96 b	2 b	0.688 b	7.66 b
	Bentazone	3.63 c	1.49 c	0.518 b	8.43 b
	Imazethapyr	3.80 bc	1.91 b	0.64 b	7.90 b
	Straw mulch	4.56 a	2.80 a	1.193 a	2.50 c
	Control	4.56 a	2.97 a	1.24 a	-
<i>I. × leucantha</i>	2,4-D+MCPA	0 d	0 e	0 c	10 a
	Pendimethalin	1.60 c	0.450 c	0.114 c	9.8 a
	Nicosulfuron	2.76 b	1.76 b	0.768 b	8.23 b
	Bentazone	2.73 b	1.81 b	0.705 b	8.33 b
	Imazethapyr	2.56 bc	1.78 b	0.865 b	7.66 b
	Straw mulch	3.36 b	1.21 b	0.50 b	8.7 ab
	Control	4.70 a	2.86 a	1.531 a	-
<i>I. hederacea</i>	2,4-D+MCPA	0 e	0 d	0 c	10 a
	Pendimethalin	2.6 d	0.90 c	0.482 b	7.6 ab
	Nicosulfuron	3.6 bc	1.20 bc	0.367 bc	8.63 ab
	Bentazone	3.1 cd	0.92 c	0.250 bc	9.03 ab
	Imazethapyr	3.7 bc	1.84 ab	0.602 b	7.23 b
	Straw mulch	4.06 ab	1.61 abc	0.394 bc	8.0 ab
	Control	4.76 a	2.37 a	1.016 a	-
<i>S. rhombifolia</i>	2,4-D+MCPA	2.2 c	0.41 b	0.145 b	6.56 b
	Pendimethalin	0 e	0 e	0 d	10 a
	Nicosulfuron	2.6 b	0.31 c	0.144 b	6.53 b
	Bentazone	0 e	0 e	0 d	10 a
	Imazethapyr	1.9 d	0.16 d	0.046 c	9.16 a
	Straw mulch	0 e	0 e	0 d	10 a
	Control	3.1 a	0.57 a	0.248 a	-

Plant height data represent the mean seedling height per pot. Different letters indicate significant differences according to the LSD test at the 5% level.

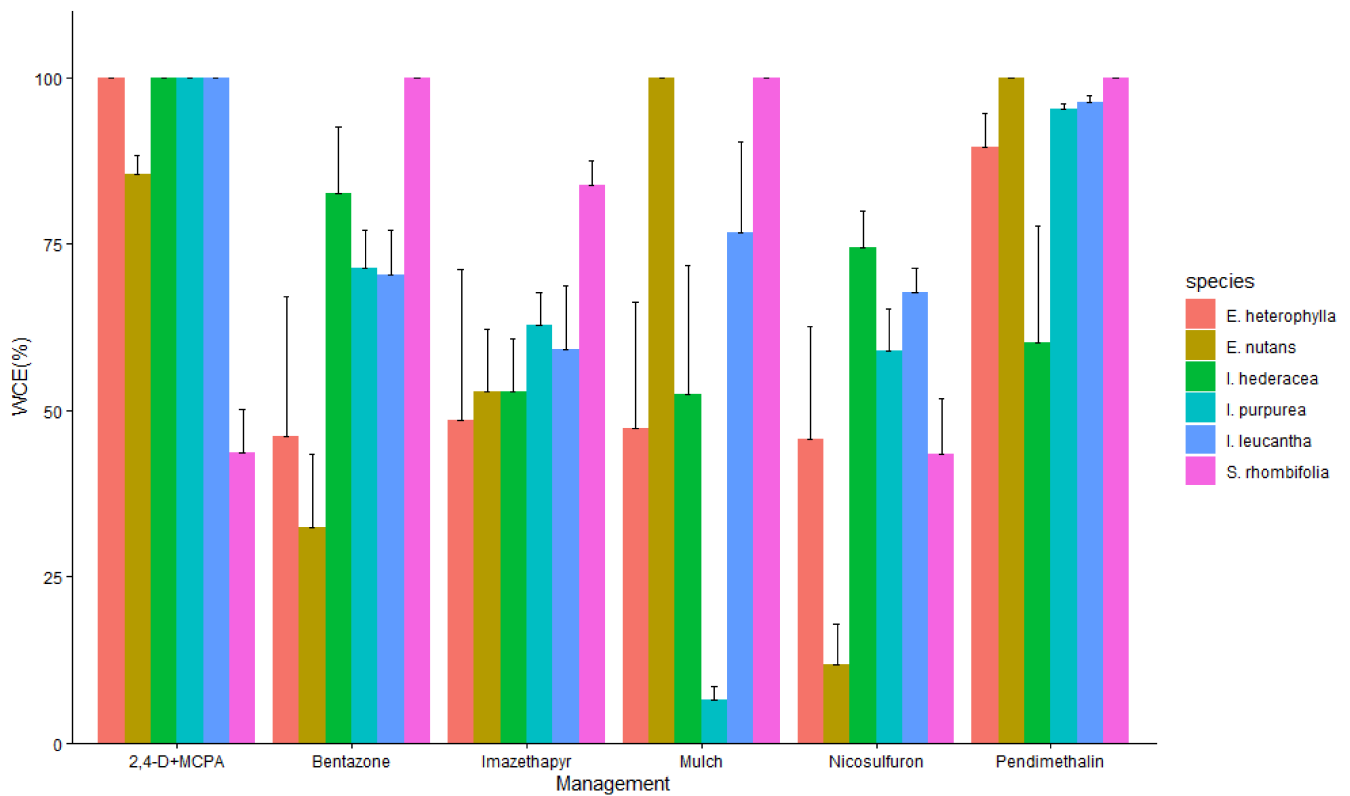


Figure 2. Weed control efficiency (%) of different management options for six alien weeds in northern Iran. Error bars show SD.

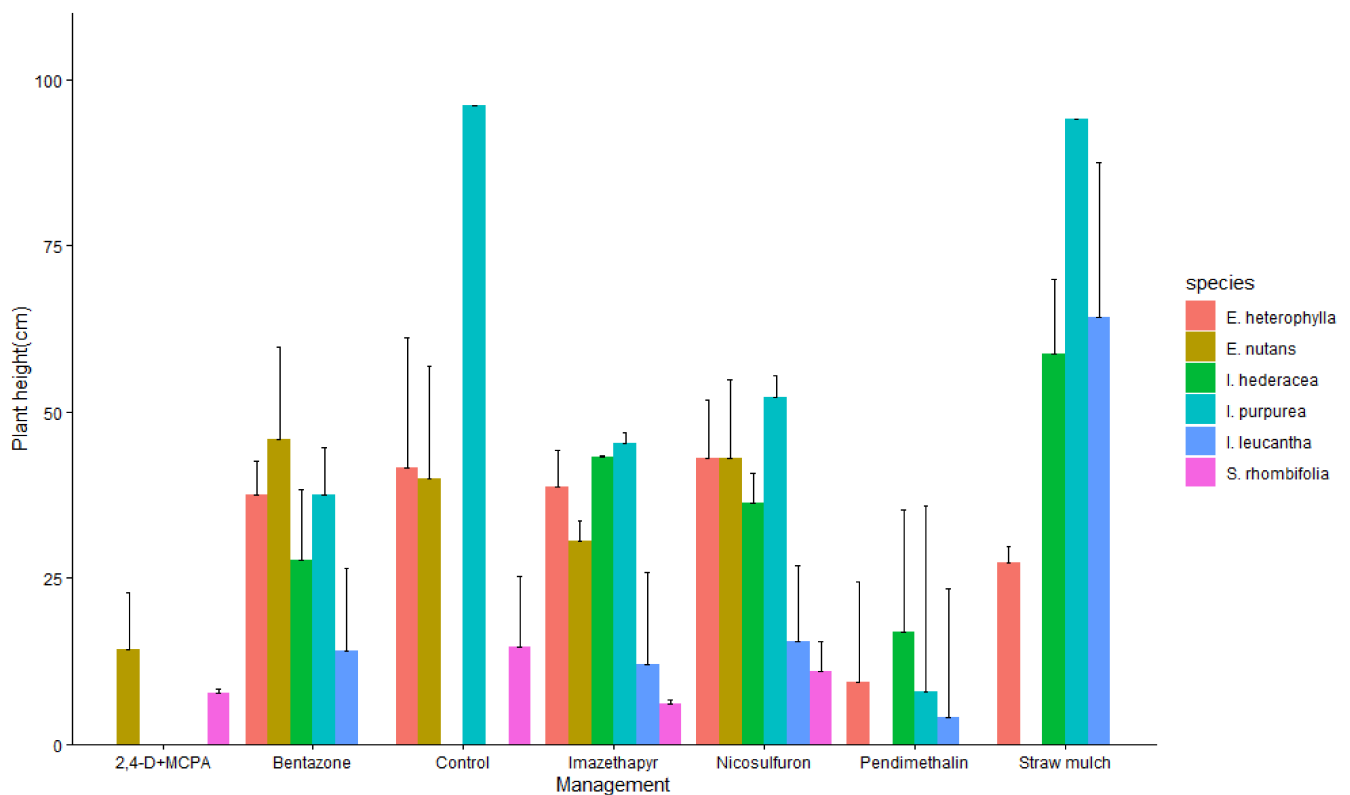


Figure 3. Differences in plant height (mean per pot) among six alien species under different management practices. Error bars indicate SD.

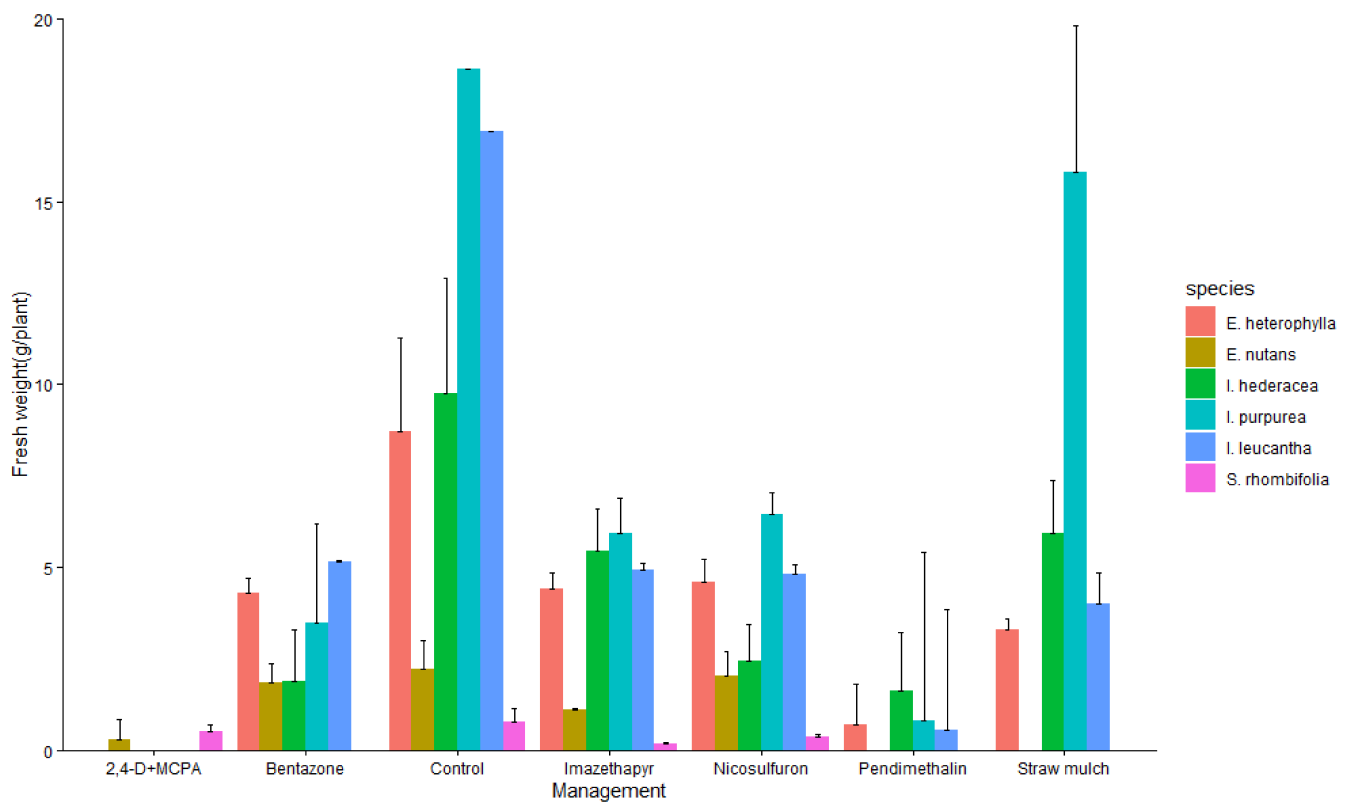


Figure 4. Differences in fresh weight (g plant^{-1}) among the six alien species under different management practices. Error bars indicate SD.

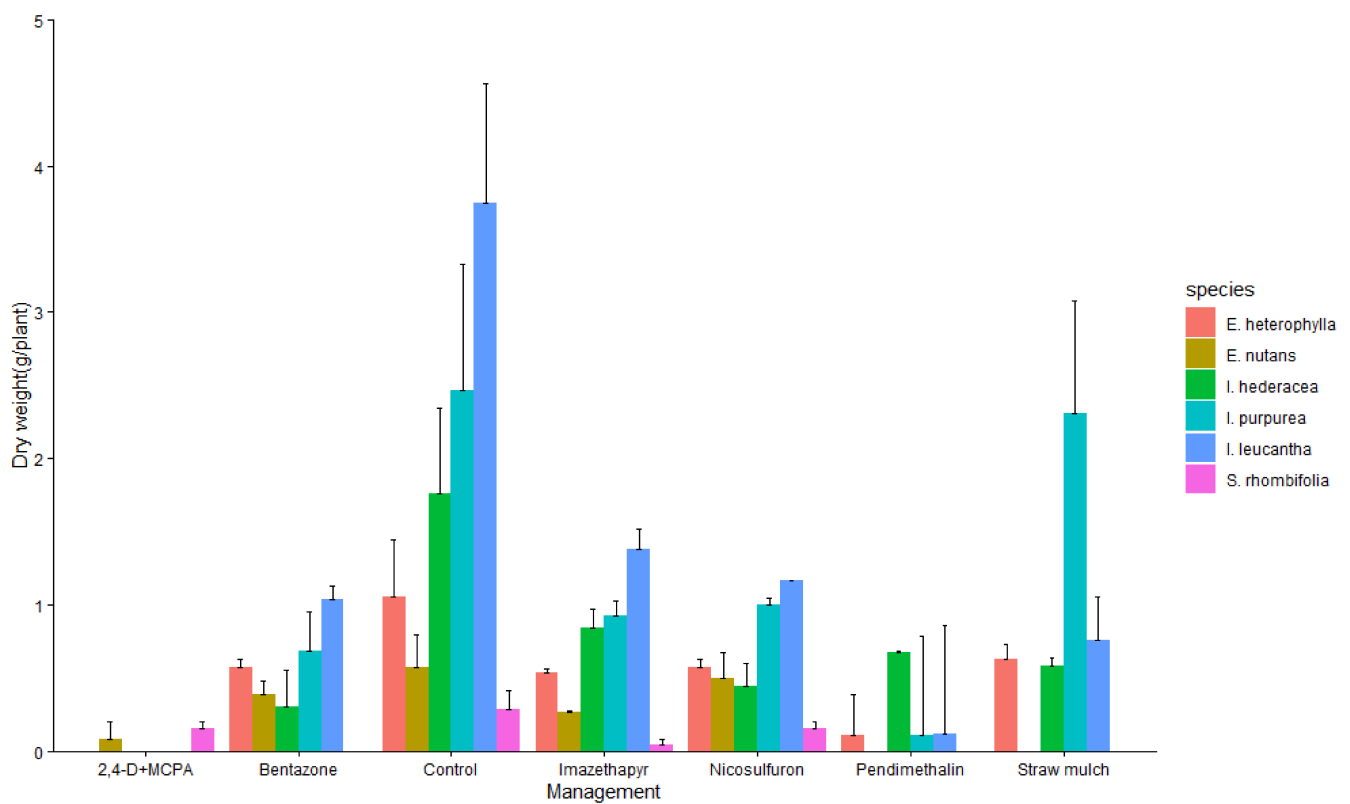


Figure 5. Differences in dry weight (g plant^{-1}) among six alien plants under different management practices. Error bars indicate SD.

3.2. Efficacy of Mulch

The response of the six invasive weeds to wheat straw mulch differed among species ranging from 20 to 100 percent (Figure 4). Mulch efficacy was high for *E. nutans* and seed-emerged *S. rhombifolia*, although the growth of *E. heterophylla* and *I. leucantha* was also limited by more than 60% (Figures 2–5). Two Ipomoea species (*I. purpurea* and *I. hederacea*) with higher seed mass (>2.5 g/100 seeds) were not affected by mulch (Figures 3 and 5). In general, wheat straw mulch at 2 tons ha⁻¹ is not recommended for Ipomoea species due to low efficiency (<20%). Differences in mulch efficacy among species were significant according to the LSD test at the $\alpha = 0.05$ level (Table 3).

4. Discussion

4.1. Herbicide Application

The management of broadleaf weeds is always challenging in crops such as soybean, canola, cotton, and sesame. Because common broadleaf herbicides such as 2,4-D+MCPA and bentazone are effective against Ipomoea species, and these species mainly infest crops such as soybean and cotton, crop rotation with maize or rice is suggested. More herbicide options were effective against *S. rhombifolia*, although nicosulfuron is not recommended because of its low efficacy (<50%). Other research indicated that the effectiveness of typical herbicides in perennial mallow species varied [35]. Due to the dual reproductive mechanism (seeds and rhizomes), herbicides used in pre-emergence are crucial for managing perennial weeds [36].

Evaluating higher doses (1.5- or 2-fold) could lead to different outcomes for the studied species. Increasing application rates within labeling restrictions may increase control of these difficult-to-control species to levels that would be of practical benefit [37]. The efficacy of the herbicide combination acifluorfen + bentazone for managing narrowleaf sida (*S. rhombifolia*) ranged from 80 to 99%, with optimal control achieved when applied to four-leaf plants [38]. Herbicides such as glyphosate, glufosinate-ammonium, and trifloxysulfuron were effective when applied at the young (four-leaf) stage, whereas a marked decline in control efficacy was observed at later developmental stages [39]. Pre-emergence metribuzin, imazaquin and post-emergence imazethapyr and glyphosate were controlled *S. rhombifolia* in glyphosate-tolerant soybean (*Glycine max*) [40]. To provide season-long control of prickly sida (*Sida spinosa* L.), application of PRE and POST herbicides is recommended in cotton fields in Greece [41]. Dinitroaniline herbicides disrupt microtubule formation, thereby hindering cell division and elongation in plants, for managing annual grasses and broadleaf weeds in corn, sorghum, soybeans, and nursery plants [42]. Other studies have identified combinations of pre- and post-emergence herbicides as the most effective options for weed management in soybean; for example, S-metolachlor + pendimethalin (pre-emergence) and fluazifop-p-butyl (post-emergence) ensured optimal weed control, minimal crop injury, and higher soybean yield in Pakistan [43].

In another study, metsulfuron + 2,4-D (2.4 + 670 g ha⁻¹) was identified as an efficient alternative for controlling *E. heterophylla*, demonstrating high control efficacy (94%) and dry mass reduction (89%) in summer crops [44]. Other studies emphasized the significance of managing this invasive species because its rapid growth as a C4 plant enhances its ability to compete for light and nutrients in farming regions [45,46]. The reduced effectiveness of nicosulfuron on *E. nutans* might be associated with the leaf surface of this species.

The surfaces of the young leaves of *E. nutans* have finely curled hairs but become hairless (glabrous) with age [47].

Additional research indicates that the chemical control of plants belonging to the genus Ipomoea leads to varying degrees of control effectiveness [48]. The varying sensitivity of

weed species to herbicides has immediate consequences for the management strategies applied in agricultural crops [49,50].

The differentiation of *Euphorbia* seedlings is relatively straightforward for agriculturists, whereas the identification of *Ipomoea* species poses substantial challenges. Therefore, proper identification of the *Ipomoea* species present in fields is essential in both fall and early summer [51]. Because *Ipomoea* control is species-dependent, early identification is extremely important for an effective control program (Supplementary Table S5). These species can be identified at early stages by cotyledon (seed leaf) shape, angle of cotyledon lobes, position of the apical meristem (bud) at emergence, and pubescence (hairs) on the stem, petiole, and first true leaf [51].

As the *Ipomoea* species (especially *I. hederacea*) has become as a troublesome weed in soybean and cotton fields, considering their tolerance and possibility of resistance to the prevalent herbicide in Golestan provinces is recommended. Imazethapyr has been a more frequently used herbicide in soybean fields in this area for more than 7 years. The cultivation of maize will allow for the use of nicosulfuron (recommended herbicide for maize), leading to a reduction in the *I. hederacea* population in the affected area. There are reports that different species of this genus were resistant to herbicides from ALS inhibitors and PPO inhibitors [52,53]. The resistance population of *I. nil* in China remained sensitive to 2,4-D-ethylhexylester and bentazone [27]. Furthermore, earlier studies have recognized genetic variation for glyphosate resistance in *I. purpurea* accessions gathered in the 1980s [54], suggesting that examining herbicide tolerance rates in closely related *Ipomoea* species (e.g., *I. purpurea* and *I. nil*) will aid in understanding their reactions to herbicides. The use of herbicides with different modes of action (MOAs), alone or in a mixture, is one of the main tools to combat resistance to a specific group of herbicides (notably those ALS inhibitors) [55].

Moreover, certain physiological and morphological traits can lead to varied reactions to the same herbicide within a single genus. For instance, three species within the same genus of *Sida* (*S. rhombifolia*, *S. glaziovii*, and *S. cordifolia*) exhibit varying traits on their leaf surfaces, possibly linked to leaf surface absorption and the species' vulnerability to herbicides [56]. The low efficiency of 2,4-D+MCPA in our study might be connected to the leaf cuticle of *S. rhombifolia*. Even if so, considering the ester formulation of this herbicide could lead to a different result. It is necessary to assess these characteristics regarding herbicide reactions of weed species from the same genus, especially when they co-occur in fields simultaneously. In general, rapid-response herbicides are required to reduce invasive plant abundance in highly invaded sites and mitigate potential negative impacts on ecosystems. However, combining non-chemical weed control with lower herbicide rates has demonstrated the potential of integrated management programs. Many studies have shown that combining herbicide application at lower rates with tillage or flaming (propane flaming) during the early growth stages of invasive plants can provide effective and sustainable control [39,57].

4.2. Efficacy of Mulch

Exploring different organic mulches at higher rates may lead to effective management of *Ipomoea* species. Organic mulches such as straw are most effective on weeds emerging from seeds and least effective on aggressive perennial weeds emerging from rootstocks, rhizomes, or tubers [10]. The dry mass of winter cover crops such as black oat, ryegrass, vetch, and forage turnip has been reported to affect the emergence of morning glory (*Ipomoea grandifolia*), with reductions of up to 65% [58]. Flax straw improved crop performance and weed suppression by reducing total weed density [59]. The densities of *Alternanthera pungens*, *Echinochloa colona*, *Tribulus terrestris*, and *Cyperus rotundus* were

affected by wheat straw mulch in maize under local rainfed conditions [60]. Weed control using mulch is generally less costly than traditional techniques (manual, mechanical, or chemical methods) because it reduces maintenance activities after planting [61]. However, combining herbicides with organic mulches, especially during pre-emergence, can improve weed control and help maintain crop health [62]. It is suggested that the effect of mulch on *S. rhombifolia* plants emerging from roots rather than seeds should be examined. *Sida rhombifolia*, as a perennial alien weed, has shown an accelerated distribution pattern from Mazandaran province toward Guilan province (Figure 1). In addition to pasturelands and orchards, *S. rhombifolia* L. is a major weed in many rice-growing areas and causes serious problems for farmers [22]. This species occurs in many cultivated fields (37 crops) and is more common in no-till or conservation tillage systems [20]. Under changing climate and cultivation systems in rice, this species has high potential to become problematic in rice farms in Iran. Climate change and limited water resources in Iran make it necessary to change the rice production system from flooded to aerobic cultivation [63,64]. Climate change has a major impact on shortening the growing season for rice and altering the timing of crop growth stages [65].

4.3. Adaptive Management Strategies

Developing adaptive management strategies requires accurate species identification, risk and impact assessment outputs, current species distribution, and climate information to determine management priorities and efficacy [66–71]. Improved information sharing and the involvement of national initiatives can support coordination for effective management. For example, tillage systems can be recommended as a control option [19]. Depending on the life cycle, seed mass, optimum emergence depth, and root system of a species, the appropriate tillage method will differ. Tillage before planting (primary tillage), false seedbed systems, blind cultivation, and inter-row cultivation are used as mechanical weed control methods [30,72,73]. The weed management strategies could be adapted to minimize the prevalence of the invasive species for reducing the undesired effects and optimizing land use by combining prevention and control practices [9]. Invasion by alien plants in agroecosystems can be best controlled by measures like crop rotation, balanced fertilization, maintenance of cover crops, intercropping diversification, and alteration in the soil's physical, chemical and biological properties by managing tillage operation [6]. The information in this article can serve as an essential reference for other countries and regions facing similar challenges. The impact of alien plants on agricultural production can be assessed, and the results of these assessments are important for formulating adaptation and mitigation measures to combat their invasion and further spread [2,17]. By understanding effective management options and changes in agricultural production, policymakers can more effectively develop policies and action plans to address the continuing negative impacts of invasive alien plants, safeguard food security, maintain farmers' livelihoods, and promote sustainable agricultural development. Coordination with the agricultural and plant health sectors, as well as the environmental sector, is crucial for the efficacy of national policies related to invasive alien species [18,74].

5. Conclusions and Further Directions

Our results highlight that appropriate management tactics differ depending on the invasive alien plant species, although pendimethalin can be considered as an excellent alternative for controlling the studied species. It also can be applied during the growing season to provide residual control of later germinating seeds.

Euphorbia nutans and *E. heterophylla*, a new invasive weed in soybean fields in northern Iran, can be controlled during crop rotation by 2,4-D+MCPA, as a post-emergence herbicide,

and mulching (2 tons ha^{−1}). The management of *Ipomoea* species was more challenging because of their growth habit and higher seed mass. Additional herbicide options (bentazone and nicosulfuron, and 2,4-D+MCPA) were effective against *I. hederacea*. By cultivating crops such as maize and rice, the population of this weed could be mitigated because broadleaf herbicides such as 2,4-D+MCPA and bentazone can be applied. Pendimethalin and bentazone were effective against *S. rhombifolia*, although the sensitivity to 2,4-D-ethylhexylester will be worth consideration. The ongoing application of imazethapyr (ALS inhibitors) in the region could lead to certain resistance levels in *Ipomoea* species. Taking this option into account will be crucial for upcoming research. The results of this study suggest that the morphology of leaf surfaces in species should be evaluated to determine the primary causes of varied responses.

Mulching and different tillage systems can be mentioned as alternative management options for species with low seed mass. Further work is needed to implement integrated management programs that remain cost-effective and sustainable tools for maintaining or enhancing ecosystem services and conservation values in the invaded areas.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/ecologies7030066/s1>, Table S1: Analysis of variance of WCE (sqrt transformation); Table S2: Analysis of variance of plant height (log transformation); Table S3: Analysis of variance of fresh weight (log transformation); Table S4: Analysis of variance of dry weight (log transformation); Table S5: Early identification keys of the three *Ipomoea* species in this study.

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