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Economic and environmental assessment of the performance of reduced rates of two post-emergence herbicides in an arid irrigated production system of central Australia: a pilot study

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Summary

The use of herbicides can add considerable costs to production practices on marginal land, and increase risks to environmental and human health. The relative performance of label and sub-label rates of the post-emergence herbicides (Amitrole T and Basta) and label rates of Roundup was compared within a benefit-cost analysis framework, in an arid irrigated production system in central Australia. Sub-label rates of Amitrole T and Basta were as effective at weed suppression as their label rates (LR); approximately 50% reduction in weed cover was recorded across the trial with both label and sub-label rates for both herbicides. The sub-label rates of Amitrole T (75% LR and 65% LR) and Basta (75% LR) had a statistically similar economic benefit-cost ratio as their corresponding LRs, and the LR of Roundup. The equivalence of Basta's sub-label rate in terms of economic efficiency is even more noteworthy if one takes into account that significantly lower amounts of the herbicide needed to be applied to achieve the level of weed suppression obtained using the label rate of Roundup. Our results suggest ways to improve the economic and environmental efficiencies of herbicide use in the arid, irrigated production systems of central Australia.

Keywords: Sub-label rates, buffel grass, arid-zone weeds, cost-benefit analysis, sustainability.

Introduction

The global trend in farming practices since the 1950s is one that is increasingly reliant on intensive and extensive chemical-inputs in the form of fertilizers, and pesticides (Matson *et al.* 1997, Tilman *et al.* 2002). Productivity in Australian agriculture mirrors global trends, increasing by nearly 250% over the past half a century, a fact at least partly attributable to reliance on chemically intensive farming (Llewellyn *et al.* 2002, Radcliffe 2002). Agriculture currently occupies approximately 54% of the total Australian land area, contributing nearly $43.27 billion per annum to the economy (ABS 2009a,b). The cost of non-fertilizer chemical inputs (e.g. pesticides, soil amendments) totalled nearly $3 billion for the period 2006–2007 (ABS 2008). While such agricultural activity has successfully increased yields of food crops this productivity has come at an environmental (e.g. impact on ecosystem services, pollution) and social cost (e.g. health risks to rural communities from chemical use), raising concerns about continuing such an approach unchecked into the future (Bellamy and Johnson 2000, Matson *et al.* 1997, Tilman *et al.* 2002).

Reducing the reliance on non-fertilizer chemical inputs by agriculture is not only environmentally beneficial, but is also economically prudent. For example, the cost of herbicide use for 2006–2007 in Australian agriculture was nearly $980 million (ABS 2008). However, numerous studies have shown that the optimal rates of application of herbicides vary in relation to environmental context (Bostrom and Fogelfors 2002) and that in many instances the required application rate of such chemical interventions are below that recommended by chemical manufacturers (Zhang *et al.* 2000). Identification of the level of chemical intervention for a given production context can therefore result in chemical use that is both effective at achieving the economic objective, and reducing risks to the environment.

Primary production in central Australia is limited by aridity, nutrient-poor soils, and remoteness that restricts access to markets and labour; however, the availability of aquifer resources (albeit of variable quality) makes sustainable irrigated agriculture feasible (Slatyer 1961). While the inherent productivity of soils may make chemical control of weeds economically viable in high quality agricultural lands, the use of herbicides is often a significant production cost in marginal, irrigation-reliant, arid-zone production systems of central Australia, and is typically only viable in high-value crops (Ellis *et al.* 2010, Faroda *et al.* 2007, Heong *et al.* 1995). As in other arid locations, weeds represent a significant impediment to irrigated agricultural production in central Australia (Ellis *et al.* 2010, Faroda *et al.* 2007, Srivastava and Singh 2005). Furthermore, the biological components of arid zone agroecosystems are often limited to fragile microphytic crusts that are vulnerable to rapid degradation through imprudent use of external chemical inputs (Bellamy and Johnson 2000, NLWRA 2002). These facts combined, highlight the need for sustainable methods of chemical intervention such as herbicide application in arid zone agriculture to achieve the suppression of weeds while realizing economic benefits from such reduced herbicide use, and a reduction in environmental risks.

The objective of this pilot study was to investigate if herbicide use can be reduced in arid production systems through use of application rates below the recommended label rates (referred to as 'sub-label' hereafter). Specifically, we asked the following questions.

How do the levels of weed suppression achieved through sub-label rate herbicide application compare with application of the recommended label rate?

Are there economic and environmental benefits of sub-label rate applications compared to applications at the label rate?

Materials and methods

Site description

The trial was conducted between June and November 2009 at the Dahlenburg Block (DB; 23°46'01.00"S, 133°52'56.30"E) of the Arid Zone Research Institute (AZRI) in Alice Springs, Northern Territory. The DB contains 60 date palms that were established in 1989.

The soil at the study site is a Kandosol, with loamy sand (LS), sandy loam (SL), sand (S), and silty loam (ZL) textures from 0 to 1.8 m depth. The pH of the soil was 7.5 from 0–30 cm and 7.4 from 30–60 cm. Nutrient analyses of the soil revealed it to be low in nitrogen (<0.05 mg kg^{-1}), extremely low in carbon (<0.4 %), moderate in phosphorus (42 mg kg^{-1}), and high in potassium (565 mg kg^{-1}). The soil had a low electrical conductivity (EC), (<2 dS m^{-1}) for the top 90 cm, and a slightly saline EC (2–4 dS m^{-1}) at 1.1–1.8 m depth. The water used for irrigation and mixing with herbicides in this study had a pH of 7.3 and a moderate EC of 2.5 dS m^{-1}.

Prior to commencement of the trial, all date palms were pruned, and the weeds at the study site were cut using a brush cutter. The canopy area of each date palm was projected and marked on the ground, and this area was the sampling unit.

Weed community

Twenty species belonging to nine families were identified as being undesirable weeds in the trial site. The orders represented were Poales (Poaceae: *Cenchrus ciliaris* L., *Cynodon dactylon* L., *Polypogon monspeliensis* L., *Dichanthium sericeum* (R.Br.) A.Camus, *Eragrostis basedowii* Jedwabn, *Sporobulus caroli* Mez., *Tragus australianus* S.T.Blake.), Asterales (Asteraceae: *Conyza canadensis* L., *Sonchus oleraceus* L., *Rhodanthe floribunda* (DC.) Paul G.Wilson, *Calocephalus knappii* F.Muell.; Campanulaceae: *Wahlenbergia tumidifructa* P.J.Sm.), Caryophyllales (Amaranthaceae: *Chenopodium truncatum* Paul G.Wilson, *Salsola tragus* L.; Portulaceae: *Portulaca oleracea* L.), Fabales (Fabaceae: *Acacia jennerae* Maiden.), Geraniales (Geraniaceae: *Erodium crinitum* Carolin), Gentianales (Gentianaceae: *Centaurium erythraea* Rafn.), Arecales (Arecaceae: *Phoenix dactylifera* L.; undesirable seedlings of date palms). Despite the high species richness of the weed flora, *C. ciliaris* (buffel grass) was the overwhelming contributor to weed cover in our study system, and therefore our results are principally applicable to this species.

Herbicide application

Herbicides selected for this study were those that were commonly recommended, available and used for the management of weeds (including grasses) in central Australia. The two post-emergence herbicides compared in this study were Amitrole T (Nufarm Australia Limited; active ingredient 250 g L^{-1} 3 amino-1,2,4-triazole and 220 g L^{-1} ammonium thiocyanate; a group F herbicide that inhibits carotenoid synthesis) and Basta (Bayer CropScience; active ingredient 200 g L^{-1} glufosinate; a group N herbicide that inhibits glutamine synthetase). For these two herbicides four rates were applied. These included the label rate (LR = Dose 1 or D1; Amitrole T (H1) LR = 11 mL L^{-1}; Basta (H2) LR = 5 mL L^{-1}), 85% of LR (D2), 75% of LR (D3) and 65% of LR (D4). In addition Roundup (Nufarm Australia Limited; post-emergence herbicide; active ingredient 360 g L^{-1} glyphosate isopropylamine salt; a group M herbicide that inhibits amino acid synthesis; LR = 13 mL L^{-1}) was used as a positive control (LR only; T0) and water (T) was used as a negative control, giving a total of ten treatments. Treatments were applied using a Solo Backpack sprayer (Model 475; Solo, Sindelfingen, Germany) at 4 bar pressure, with a flat spray-tip nozzle (110°) delivering 1.85 L per minute. Treatments were applied onto the weeds in the projected canopy area on three occasions four weeks apart. This interval is the average of the recommended application intervals for the different herbicides used in the trial. The LR indicated above for each of the herbicides corresponds to the spot-spraying label rate for major perennial grass weeds. We deemed this rate to be more representative than the boom application rate given that we were monitoring weed cover in the area defined by the date palm canopy.

Data and statistical analysis

The trial used a completely randomized design, with six replicates for each of the treatments. Weed cover was estimated as a proportion (%) of the projected canopy area of each of the date palms prior to each herbicide application, and four weeks after the final application. Cover was estimated as a consensus estimate of three independent observers. Economic and environmental benefit-cost ratios were also calculated after each application. An economic benefit-cost ratio (EcBCR) was calculated at each sampling time as the percent reduction in cover (relative to initial weed cover) per unit cost ($) of herbicide used in each treatment, while an environmental benefit-cost ratio (EnBCR) was calculated at each sampling time as the percent reduction in cover per unit volume (mL) of herbicide used in each treatment. The EnBCR assumes that reducing the volume of herbicides into the environment is beneficial.

The data were analyzed using repeated measures ANOVA with herbicide treatment as the between subject factor, time as within subject factor, and weed cover, EcBCR or EnBCR at each of the sampling times as the dependent variable. Since EcBCR and EnBCR were calculated relative to initial weed cover, they were only analyzed for subsequent sampling times. Where significant treatment effects ($P < 0.05$) were detected, protected posthoc pairwise comparisons were made using Tukey's HSD test. All analyses were done using Statistix 9 (Analytical Software, Florida).

Results

Weed cover

Weed cover differed across the different herbicide treatments ($F_{9,50} = 3.15$, $P = 0.004$) and over time ($F_{3,150} = 132{,}04$, $P < 0.001$), but these differences were not independent of each other (Treatment*Time: $F_{27,150} = 3.04$, $P < 0.001$). Posthoc pairwise comparisons revealed that at the start of the trial (Time 0) there was no difference in weed cover between the herbicide treatments (Figure 1). At both one month after the first herbicide application (Time 1), and one month after the second herbicide application (Time 2), treatment effects could be grouped into three groups. Treatments H1D1, H1D2, H1D3 and T0 had significantly lower cover than the negative control (T), while all other treatments had an intermediate level of cover (Figure 1). A month after the third application (Time 3) all treatments other than H2D4 had a relatively similar weed cover that was lower than T; H2D4 did not differ in cover from other treatments or T. Comparisons of weed cover for a given treatment across different sampling times revealed that after the first application, all treatments except H2D4 caused a significant

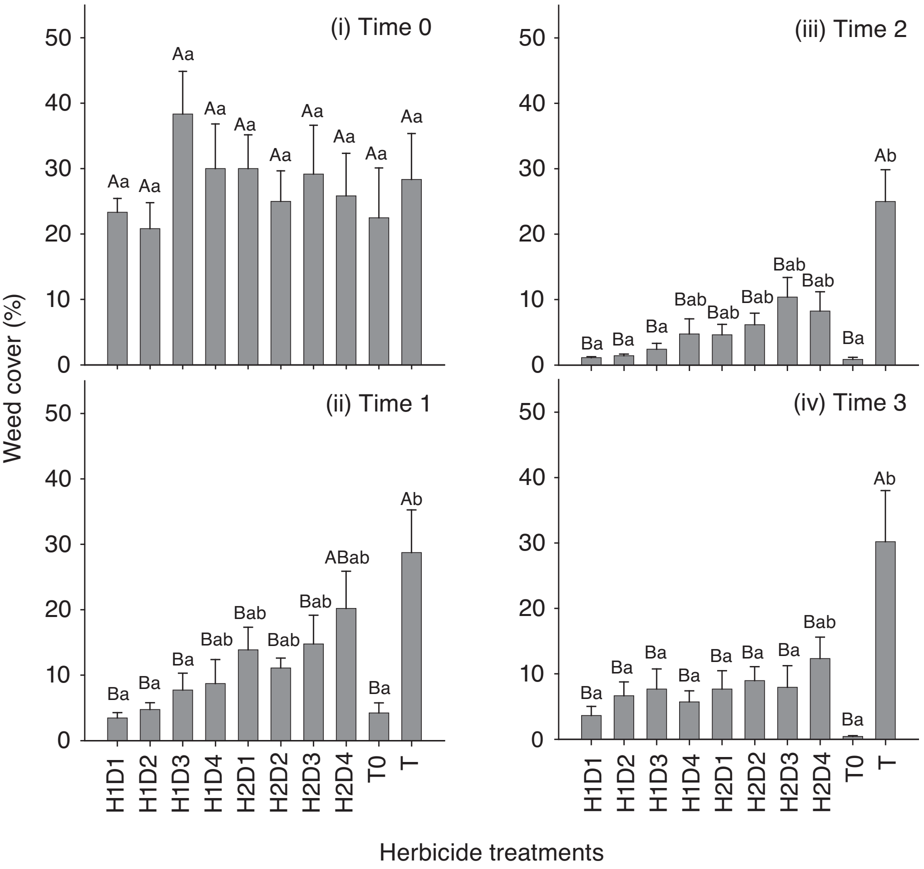

Figure 1. Effect of herbicide treatments on weed cover (%) (i) prior to application (Time 0), (ii) one month after the first application (Time 1), (iii) one month after the second herbicide application (Time 2) and (iv) one month after the third application (Time 3). Lettering indicates posthoc pairwise comparisons using Tukey's HSD test. Lower case letters enable comparison across herbicide treatments for a given time, while upper case letters enable comparisons across time for a given herbicide treatment. Bars with the same letter are not statistically different from each other. Legend for Herbicide Treatment: H1 = Amitrole T, H2 = Basta; D1 = label rate (LR), D2 = 85% LR, D3 = 75% LR and D4 = 65% LR; T = water (negative control) and T0 = Roundup at LR (positive control).

reduction in cover, and no further reductions in cover were observed with subsequent herbicide applications (Figure 1). H2D4 required two applications before causing a significant reduction in cover relative to Time 0 (Figure 1). The application of the negative control (T) did not change weed cover over time (Figure 1).

Economic benefit-cost ratio (% reduction in cover per $ of herbicide)

There was a significant difference in EcBCR between the herbicide treatments ($F_{8,45}$ = 2.70, P=0.016) and over time ($F_{2,90}$ = 29.93, P<0.001), but these differences were not independent of each other (Treatment*Time: $F_{16,90}$=2.65, P=0.002). At Time 1, Roundup (T0) had the highest average EcBCR that was significantly different from H2D4 but not from the rest of the treatments (Figure 2). At Time 2, T0 continued to have the highest EcBCR that was significantly different from H1D1, H1D2, but not from the rest of the herbicide treatments (Figure 2). After the third application (Time 3) Roundup sustained its high EcBCR relative to H1D1, H1D2, H2D1, H2D2 and H2D4, but did not statistically differ from the other treatments (Figure 2). Comparisons within treatments across different sampling times revealed that the EcBCR of most treatments were maintained at the same level as that after the first herbicide application (Figure 2). The doses D3 and D4 of Basta (H2) were an exception to this. H2D4 had an improved EcBCR at Time 2 and Time 3 relative to Time 1 (Figure 2). H2D3 had an improved EcBCR at Time 3 relative to Time 1, with the reduction in cover per $ of active ingredient at Time 2 being intermediate to that at Time 1 and Time 3 (Figure 2).

Environmental benefit-cost ratio (% reduction in cover per mL of herbicide)

There was a significant difference in EnBCR across time ($F_{2,90}$ = 26.30, P <0.001), but these differences were not independent of treatment (Treatment*Time: $F_{16,90}$ = 3.45, P <0.001) even though treatment effects were not statistically different from each other ($F_{8,45}$ = 1.70, P = 0.124) . At Time 1 and Time 2, there was no difference in EnBCR across treatments (Figure 3). At Time 3, H2D3 had a higher EnBCR than H1D1 and H1D2, with other treatments having an intermediate EcBCR (Figure 3). Comparisons of EnBCR for treatments across times revealed that at Time 2 H2D4 had a significantly higher reduction in weed cover per mL of herbicide, an effect that was sustained at Time 3 (Figure 3). The environmental benefit for H2D3 is not apparent until Time 3, with the reduction in cover per mL of herbicide at Time 2 being intermediate between that at Time 1 and Time 3 (Figure 3). The EnBCR of applying the label rate of Basta (H2D1) showed an interesting trend in that there was a significant improvement in reduction in cover per mL of herbicide at Time 2 relative to Time 1; however the EnBCR at Time 3 declined and was statistically similar to that at Time 1 (Figure 3).

Discussion

Sustainable agriculture in central Australia is challenged by considerable production costs associated with aridity, nutrient inputs to compensate for poor soil quality, poor water quality, and remoteness and the associated costs of market access. The availability of adequate groundwater for irrigation is one of the main drivers of the pursuit of agriculture in central Australia. However, one of the consequences of reliance on localized irrigation of high frequency is an increase in weed density, resulting in increased weed-crop competition that affects profitability of farms. As elsewhere, central Australian growers rely on herbicides to manage weeds in their production systems. But given the relatively higher production and market access costs of central Australian growers, any assistance with the reduction in input costs would potentially be beneficial.

Reduction in herbicide use is not just economically beneficial, but environmentally prudent. So it is not surprising that methods to improve the efficiency of herbicide use has been pursued with some vigour by agricultural researchers and herbicide manufacturers alike in recent times (Bostrom and Fogelfors 2002, Monteiro and Moreira 2004, Zhang *et al.* 2000, Zoschke 1994). Our results show that sub-label rates of herbicides can be as effective as label-rates in suppressing weed densities in arid, irrigated production systems in central Australia. Of particular significance is the fact that a reduction by up to 35% is possible in the application of post-emergence herbicides. The sub-label rates of Amitrole T (75% LR and 65% LR) and Basta (75% LR) not only had a statistically similar economic benefit-cost ratio to

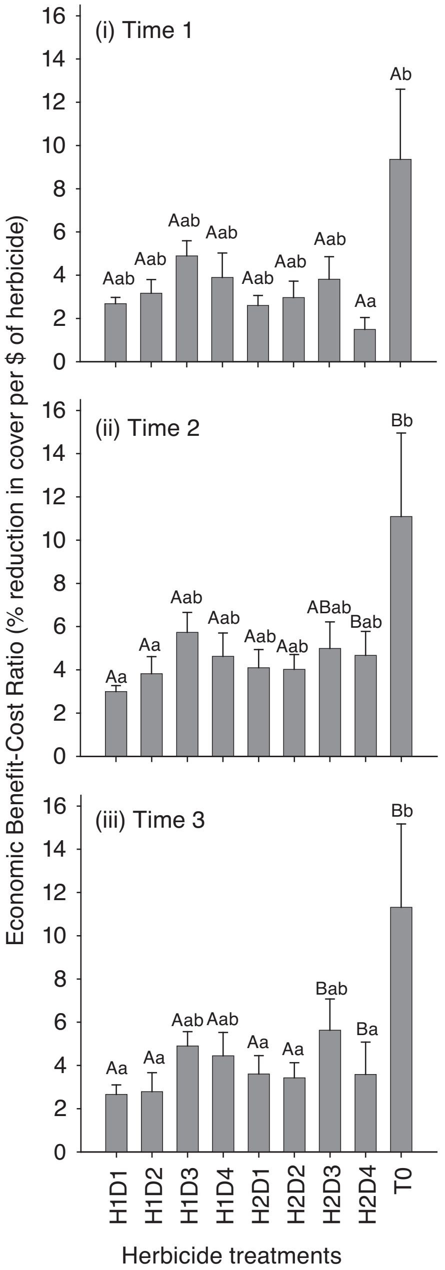

Figure 2. Comparison of herbicide treatments in terms of their Economic Benefit-Cost Ratio (reduction weed cover relative to initial weed cover per $ of herbicide) (i) one month after the first application (Time 1), (ii) one month after the second herbicide application (Time 2) and (iii) one month after the third application (Time 3). Lettering indicates posthoc pairwise comparisons using Tukey's HSD test. Lower case letters enable comparison across herbicide treatments for a given time, while upper case letters enable comparisons across time for a given herbicide treatment. Bars with the same letter are not statistically different from each other. Legend for Herbicide Treatment: same as for Figure 1.

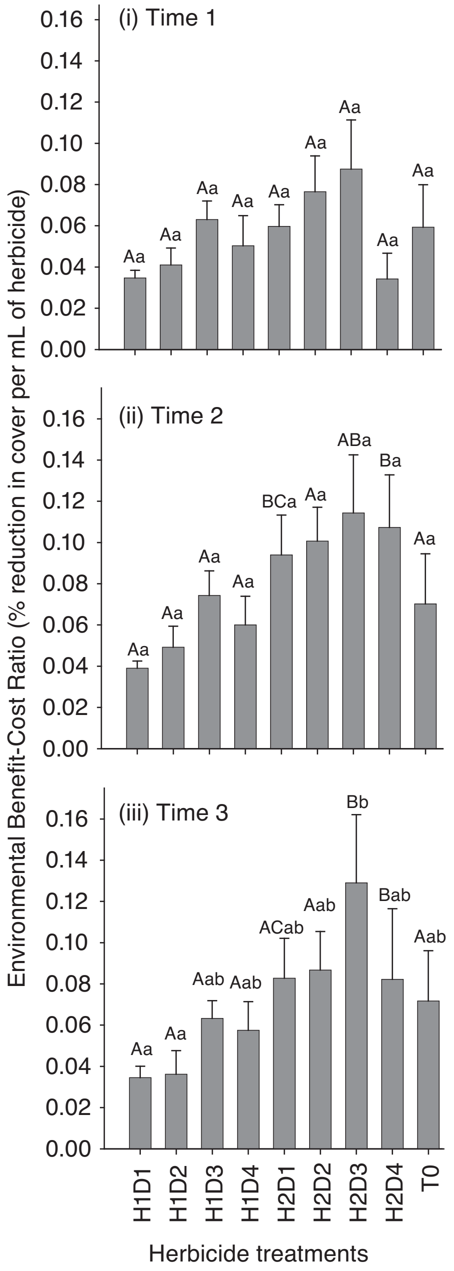

Figure 3. Comparison of herbicide treatments in terms of their Environmental Benefit-Cost Ratio (reduction weed cover relative to initial weed cover per mL of herbicide) (i) one month after the first application (Time 1), (ii) one month after the second herbicide application (Time 2) and (iii) one month after the third application (Time 3). Lettering indicates posthoc pairwise comparisons using Tukey's HSD test. Lower case letters enable comparison across herbicide treatments for a given time, while upper case letters enable comparisons across time for a given herbicide treatment. Bars with the same letter are not statistically different from each other. Legend for Herbicide Treatment: same as for Figure 1.

their respective label rates, but also to the label rate of Roundup. The equivalence of Basta's sub-label rate in terms of economic efficiency is even more noteworthy if one takes into account that significantly lower amounts of the herbicide needed to be applied to achieve the level of weed suppression as the label rate of Roundup.

We advocate caution in viewing these results solely to compare the relative efficacy of herbicides; the herbicides used in the trial have different modes of action, different active ingredient concentrations in herbicide formulations, and are therefore different in terms of the nature of the risks they pose. The utility of our results are in the demonstration that sub-label rates can provide the same level of benefit as the recommended label rate. Ascertaining the extent to which reduction from the LR is possible is therefore a useful way forward to enhance efficient and safe use of chemical weed control. More sophisticated approaches are possible for adjusting herbicide doses based on weather and weed density (e.g. Nordblom *et al.* 2003), and our study suggests that they would be worthwhile exploring in arid zone production systems to further improve economic and environmental efficiencies.

While the use of sub-label rates can reduce herbicide costs/risks to the grower, the farm, and the environment, it has the potential to add risk to the production system as well. In particular, if sub-label rates are also sub-lethal, repeated applications of the same herbicide would increase the likelihood of develop of herbicide resistance among the weed flora (Vila-Aiub and Ghersa 2005). Given that our results show that sub-label and label rates of herbicides in three different herbicide groups (based on mode of action) can be equally effective in weed suppression, integrating their use, coupled with careful long-term monitoring of resistance status among weeds in the production system, would be a prudent step to mitigate the risk of resistance development while maintaining the economic and environmental benefits.

This pilot study did not investigate the effects of weed competition on yield, because our interest was principally in comparing the relative performance of sub-label and label rates in terms of suppressing weed density. Subsequent research that extends this work in arid environments should link the performance of sub-label herbicide applications with weed suppression thresholds linking weed competition and yield of specific crops, and replicate this approach over multiple sites and over multiple growing seasons. While our economic and environmental benefit-cost assessment was a first-step, more sophisticated approaches that examine the reduction in input costs from reduced herbicide use within the overall context of the costs of the production system are needed in subsequent studies. Additional avenues for investigation also include undertaking a benefit-cost analysis of sub-label rates of Roundup (given its ubiquity and competitive price), and the development of an integrated weed management strategy combining sub-label chemical control with other methods of weed management.

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