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Commentary

MSMA: Knowledge Gaps to Aid Appropriate Regulation of an Efficacious Herbicide

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Core Ideas

- MSMA is an arsenic-based herbicide currently registered in cotton and turfgrass.
- Will continued MSMA use threaten human and environmental health?
- Discrepancies about environmental fate exist among field and laboratory research.
- Factors that influence As species transformation should be further elucidated.
- Management plans should be devised where MSMA is used.

Abstract: Monosodium methyl arsenate (MSMA) is an efficacious postemergence herbicide commonly used in cotton (*Gossypium hirsutum* L.) and turfgrass systems. Concerns have arisen about potential adverse effects of MSMA-derived arsenic on human and environmental health. The USEPA enacted a phase-out of MSMA and other organic arsenical pesticides in 2006, although subsequent agreements allow for its continued use until a review is complete in 2019. Additional research is needed to further characterize MSMA environmental fate and species transformation kinetics in cotton and turfgrass systems of varying edaphic conditions, as there are current knowledge gaps and discrepancies in previous reports. Improved understanding of MSMA environmental fate under real-case conditions will allow regulatory agencies to devise appropriate regulations and management plans to ensure environmental and human health are protected.

Monosodium methyl arsenate (MSMA) is an organic arsenical postemergence herbicide whose reregistration by the USEPA is in question due to concerns about arsenic (As) loading to the environment and subsequent threats to human and environmental health. It is valuable from an agronomic perspective because it controls many common and troublesome weed species, is economical, and offers an alternative mode of action that aids producers with herbicide resistance management. In 2006, the USEPA enacted a phase-out of all organic arsenical pesticides, including MSMA, making them ineligible for reregistration (USEPA 2009). As part of a subsequent 2009 agreement, however, an MSMA registration review was initiated in 2013 to consider all currently registered use sites; once complete in 2019, the USEPA Office of Pesticide Programs will make a final ruling about future MSMA use. The sale, distribution, and use of MSMA will continue with imposed restrictions on golf courses, sod farms, and highway rights-of-way; however, MSMA use is still permitted in cotton (*Gossypium hirsutum* L.) with fewer restrictions until the USEPA Integrated Risk Information System review on inorganic As is complete and evaluated by the National Academy of Sciences (OAPTF, 2013; USEPA 2013). Despite this plan, current knowledge about the environmental fate of MSMA-derived As is limited, and numerous questions needed to guide reregistration decisions remain unanswered.

Effective herbicide management must balance the dual needs of agronomic productivity and environmental sustainability. Current debate about MSMA reregistration serves as a prime example of the challenges associated with decision-making in the face of uncertainty about the fate of chemicals in the environment. The purpose of this commentary is to outline the current state of knowledge concerning MSMA-derived As accumulation, cycling, and pollution potential and to identify areas where additional research is needed so that management decisions can be better designed to ensure environmental and human health aren't threatened by

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future MSMA use. Three key questions to guide research into As environmental fate after MSMA application follow.

What Is the Ultimate Fate of Arsenic following MSMA Application within Different Agronomic Systems and Environments?

Field, laboratory, and greenhouse studies have been used to characterize the environmental fate and behavior of As following MSMA use in various agronomic systems; however, different conclusions about resulting risks have often been derived based on the specific mode of study. In laboratory studies, many of which have used excessive MSMA loading rates and low soil-solution ratios, rapid species transformation and redistribution of As from solid to aqueous phases have been observed (Shimizu et al., 2011a,b), whereas field research using recommended MSMA application rates has suggested tight cycling of As within the soil-plant-water system (Matteson et al., 2014; Mahoney et al., 2015b). Column and field studies evaluating As leaching potential following MSMA application have shown elevated porewater As concentrations to 40 cm depth but not to 76 cm in established turfgrass systems (Feng et al., 2005; Matteson et al., 2014; Mahoney et al., 2015a), although the extent of downward migration of As to groundwater depends on edaphic and management conditions. In Florida, the one state where MSMA use is now banned in turfgrass systems, elevated groundwater As (up to 815 μg/L) near golf courses and As accumulation in golf course lake systems have been reported (Wiegand 1999; Pichler et al., 2008). Future research needs to more systematically reconcile how MSMA use patterns impact As fate and potential threats to water quality and environmental health. In particular, studies are needed that quantify MSMA loading limits and As mass balance for different soils, agronomic systems, and environments, particularly with reference to natural background As levels and historic land uses that may have loaded As into the local environment.

What Are the Rates and Extent of MSMA Transformation to Inorganic Arsenic?

Arsenic from MSMA applications may transform and exist in various valence states as inorganic or organic forms. Arsenic speciation affects its mobility and toxicity, which are paramount factors in the regulatory decisions currently being made about the reregistration eligibility for organic arsenical pesticides (Páez-Espino et al., 2009; Mahoney et al., 2015a). Recent research in both laboratory and controlled greenhouse/column studies has demonstrated that considerable demethylation of MSMA may occur within the first month after application (Feng et al., 2005; Shimizu et al., 2011b; Mahoney et al., 2015b). However, the extent, kinetics, and pathways of As species transformation remain poorly elucidated for complex, real-case field environments. Moreover, although inorganic MSMA degradates, including arsenite [As (III)] and arsenate [As(V)], are generally more toxic than organic As species (Liu et al., 2001; Hughes, 2002), inorganic As species tend to be adsorbed to soil minerals more than organic As species (Lafferty and Loeppert, 2005; Shimizu et al., 2011a), making them less mobile and potentially less likely to contaminate groundwater or surface water. Specific factors that affect the species transformation and subsequent binding affinity of As are not well elucidated. These factors include, but are not limited to, soil texture, metal-oxide content, organic matter content, moisture, depth to water table, and redox potential, and each of these may be further modified by plant type and field management. Future research could better establish how soil conditions and crop management strategies influence As species transformation and the potential for As risks to human and environmental health following MSMA use.

How Should Management Plans Account for Current and Potential Future Risks Due to MSMA Application?

Repeated use of MSMA, even at labeled rates, can cause As accumulation within surface soils, making such areas vulnerable to contamination issues should soil loading limits be exceeded or land uses altered. For instance, elevated As in rice (*Oryza sativa* L.) from the southeastern United States has been attributed to conversion of old cotton fields to rice fields, where the historic use of arsenical pesticides, the saturated rice-growing conditions, and the propensity for rice to take up As have conspired to mobilize accumulated soil As and increase rice grain concentrations (Potera, 2007; Williams et al., 2007). Accordingly, when considering MSMA use, management plans and restrictions should be imposed to incorporate future risks for vulnerable agronomic and nonagronomic systems. To minimize As loading to the environment, MSMA should be used as part of comprehensive management plans that utilize integrated pest management strategies such as lower application rates at optimal timings. Water management strategies that control irrigation and drainage and restrict application of MSMA in areas with a shallow water table or when heavy rains are forecasted can help reduce As runoff, leaching potential, and species conversion (Mahoney et al., 2015a). Additionally, food crops that accumulate As, such as rice and apples, should not be grown in areas where MSMA use was extensive (Abedin et al., 2002), and nonagronomic land uses for which human–soil contact probabilities are high, such as housing subdivisions, schools and playgrounds, should only be developed after monitoring and remediation have taken place. Future research should evaluate how various management strategies for current MSMA use areas—including turfgrass, highway rights-of-way, and cotton—influence As mass balance and efflux, as such cross-system comparisons have not been performed. Work is also needed to communicate the potential for As risks to growers and developers of sites where MSMA was previously used, such as in former cotton and turfgrass fields.

Future Outlook

Although much research has been done characterizing MSMA-derived As fate and behavior, key questions regarding MSMA loading limits, species transformation, and management strategies constrain our ability to effectively use MSMA while minimizing off-target risks to human and environmental health. If MSMA use is to continue, it should be done only with appropriate scientifically derived restrictions, and it should not be used in all geographies, cropping systems, or management scenarios. Further, from an environmental contaminant perspective, the view that MSMA-derived As behaves differently in cotton production compared to golf courses, sod farms, and highway rights of way is not supported by the body of knowledge, and this should be considered before additional regulations are implemented.

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