

Adjuvants and Herbicide Dose-Reduction Approaches for Enhancing Weed Control in Oil Palm Plantations: Evidence and Research Priorities

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ABSTRACT

Effective weed management in oil palm (*Elaeis guineensis*) plantations depends heavily on herbicides, but tropical rainfall, dense canopies, hard spray water, and waxy weed surfaces can reduce spray retention, absorption, and translocation. This review synthesises mechanistic and field evidence on herbicide adjuvants, including surfactants, and commercial herbicide dose-reduction approaches relevant to oil palm and comparable tropical perennial systems. Adjuvants improve spray characteristics or biological performance, while surfactants are a major adjuvant subclass that enhances wetting, spreading, and cuticular contact. Field studies report improved control of difficult weeds, including *Alocasia* species, and related approaches are being evaluated against *Eleusine indica* and other resistant plantation weeds. Commercial herbicide dose-reduction products, including WEED Solut-ion® as a product marketed by its manufacturer as a “reductant”, have shown potential to maintain acceptable weed control at reduced herbicide rates under selected conditions. However, the evidence remains geographically concentrated and partly dependent on manufacturer documentation, requiring independently replicated multi-site validation. Appropriate additive use may reduce chemical inputs and off-target losses while supporting broader Environmental, Social and Governance (ESG) objectives and relevant United Nations Sustainable Development Goals (SDGs); MSPO and RSPO remain relevant where certification-specific compliance is directly concerned. Priority research includes multi-environment validation of dose-reduction products, life-cycle and ecotoxicological assessment of bio-based formulations, herbicide-additive compatibility under tropical conditions, and practical decision-support tools. Overall, additive-assisted herbicide application is promising when product selection is evidence-based and matched to herbicide chemistry, weed biology, water quality, and field conditions.

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1. INTRODUCTION

Weed infestation poses a major threat to productivity in oil palm (*Elaeis guineensis*) plantations, where herbicides are widely relied upon because they provide broad-spectrum control at relatively low cost (Adham et al., 2020; Wibawa et al., 2010). However, prolonged reliance on a limited number of herbicide modes of action has resulted in widespread resistance in key weed species and increased concerns for environmental contamination from spray drift, runoff, and residual deposits (Baćmaga et al., 2024; Beckie et al., 2019; Hicks et al., 2018; Rigon et al., 2020). These concerns have also attracted greater scrutiny from sustainability certification bodies and regulatory authorities (FGV Holdings Berhad, 2024; Parish et al., 2019). As a result, there is a growing interest in weed management approaches that improve herbicide efficiency while reducing environmental impact and reliance on increasing application rates.

Herbicide adjuvants, including surfactants, are non-herbicidal additives designed to enhance herbicide performance by improving spray retention, absorption, penetration, and stability (Green & Foy, 2004; Hazen, 2000). These additives have been extensively studied in row crops and temperate agricultural systems, where their capacity to maintain or improve efficacy at lower application rates is well documented (Abbas et al., 2018; Idziak et al., 2023). In contrast, their use and performance in tropical perennial crops, such as rubber, cocoa, and coffee, have received considerably less attention, and their role in oil palm plantations has yet to be systematically evaluated.

More specifically, four unresolved issues limit evidence-based recommendations for oil palm plantations: (i) the scarcity of oil-palm-specific field comparisons among different additive classes; (ii) limited independent validation of commercial herbicide dose-reduction products and proprietary adjuvant blends; (iii) insufficient understanding of how herbicide chemistry, weed leaf traits, spray-water quality, and tropical rainfall conditions interact to determine additive performance; and (iv) inadequate information on the environmental, ecotoxicological, and economic consequences of reducing herbicide rates through additive use. Addressing these gaps is necessary to distinguish broadly applicable principles from product- or site-specific claims and to develop practical, evidence-based recommendations for sustainable weed management in oil palm plantations.

Therefore, this review addresses these gaps by examining the classification, functions, and mechanisms of herbicide adjuvants, including surfactants, together with commercial herbicide dose-reduction approaches. It synthesises current evidence on their effectiveness in oil palm and comparable cropping systems, assesses their potential to reduce herbicide

Several reviews have examined herbicide resistance and integrated weed management (Beckie et al., 2019; Kumar Gupta et al., 2022; Riemens et al., 2022), but few have considered the role of herbicide adjuvants, including surfactants, and commercial herbicide dose-reduction approaches in tropical perennial systems. Evidence remains scattered across studies that differ in crop types, e.g., maize (Abbas et al., 2018); oil palm (Jabit et al., 2022), environmental conditions, and herbicide formulations (Dilipkumar et al., 2020; Travlos et al., 2017), making it difficult to draw conclusions relevant to oil palm plantations. There has been little effort to synthesise how these additives interact with major herbicide classes used in oil palm, such as glyphosate, glufosinate, and paraquat alternatives, or to evaluate their contribution to more sustainable weed management.

The central problem addressed by this review is the lack of sufficiently integrated, oil-palm-specific evidence to determine when herbicide adjuvants and dose-reduction approaches can reliably improve weed control without compromising efficacy, crop safety, resistance stewardship, or environmental performance.

inputs and environmental risks, and considers their role in supporting sustainable weed management. Based on the available evidence, the review also identifies key knowledge gaps and highlights future research priorities on additive-based weed management in oil palm plantations.

Accordingly, this review addresses four research questions:

- (1) Which adjuvant classes and herbicide dose-reduction approaches have been evaluated for improving herbicide performance in oil palm and comparable tropical cropping systems?
- (2) Through which physicochemical and biological mechanisms do these approaches influence spray deposition, retention, cuticular penetration, absorption, and translocation?
- (3) What field evidence supports their ability to improve weed control, maintain efficacy at reduced herbicide rates, and provide operational or economic benefits under tropical conditions?
- (4) What evidence gaps currently limit safe, sustainable, and generalisable recommendations, particularly with respect to independent validation, crop safety, environmental effects, and cost-effectiveness?