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Efficacy of Isopropylamine glyphosate 350 g/l and 2,4-d dimethylamine 150 g/l herbicide mixtures on weeds in immature Oil palm (*Elaeis guineensis* Jacq.)

Yayan Sumekar, Renaldi Alfrezzy, Intan Ratna Dewi Anjarsari
Faculty of Agriculture, University of Padjadjaran, Jl. R. Bandung-Sumedang, Jatinangor, West Java, Indonesia

Abstract
Weed competition during the immature phase represents a critical constraint to oil palm (*Elaeis guineensis* Jacq.) productivity, with potential yield losses exceeding 50% of production capacity. This field study evaluated the efficacy and crop safety of Isopropylamine Glyphosate (350 g/L) and 2,4-D Dimethylamine (150 g/L) herbicide mixture at five application rates (1.50, 2.25, 3.00, 3.75, and 4.50 L/ha) in immature oil palm plantations in West Java, Indonesia. The trial employed a Randomized Block Design with seven treatments, including manual weeding and untreated controls, replicated four times. Vegetation analysis identified *Strachytapheta jamaicensis* (SDR 26.60%), *Miconia crenata* (15.79%), and *Cyperus rotundus* (11.36%) as dominant weed species. Weed biomass and phytotoxicity assessments were conducted at 4, 8, and 12 weeks after application. Results demonstrated that all herbicide rates achieved over 96% reduction in *S. jamaicensis* biomass, with rates ≥2.25 L/ha maintaining effective long-term suppression. Complete control of *M. crenata* was achieved at rates ≥2.25 L/ha, while the more recalcitrant *C. rotundus* required rates ≥3.75 L/ha for total suppression. Importantly, no phytotoxic symptoms were observed on immature oil palms at any application rate throughout the 12-week observation period. Manual weeding demonstrated inferior performance compared to chemical control, particularly for perennial species. The application rate of 3.75 L/ha is recommended as optimal for achieving comprehensive weed control while ensuring crop safety and economic efficiency in immature oil palm cultivation.

Keywords: Isopropylamine glyphosate, 2,4-D dimethylamine, Oil palm, phytotoxicity, weeds

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a plantation commodity that occupies a central position in Indonesia's economic structure, serving as a strategic pillar of national economic resilience. As the world's largest producer of Crude Palm Oil (CPO), Indonesia consistently dominates global supply, with total production reaching 47 thousand tons in 2024 (Badan Pusat Statistik, 2025) [1]. This dominance directly supports the national trade balance. In 2024, the palm oil sector was recorded as one of the largest contributors to non-oil and gas foreign exchange, with an export value reaching USD 27.75 billion (Gabungan Pengusaha Kelapa Sawit Indonesia, 2025) [2]. Its significant contribution to the national Gross Domestic Product (GDP) further underscores its vital role in maintaining stability and driving Indonesia's macroeconomic growth (Kusuma *et al.*, 2024) [3]. Given its crucial role, efforts to maintain sustainability and enhance the productivity of oil palm plantations are imperative, where optimal cultivation practices serve as the key determinant, particularly during the early stages of plant growth.

One of the most critical periods in the oil palm life cycle is the immature phase, which lasts approximately 12–48 months after planting (Mardhika & Sudradjat, 2015) [4]. This phase represents a long-term investment period, the success of which determines the performance and productivity of the plant during the future mature phase. Optimal vegetative growth during the immature phase, such as increases in stem girth, frond number, and canopy area, is positively correlated with earlier fruiting and higher production potential (Suhartono *et al.*, 2023) [5]. Any biotic stress occurring during this phase can retard growth, prolong the immature period, and ultimately delay economic returns for the plantation (Corley & Tinker, 2015) [6]. Therefore, the management of factors influencing the growth of young palms is a primary priority in plantation management.

The presence of weeds constitutes one of the most detrimental limiting factors in oil palm cultivation during the immature phase. The incomplete canopy closure allows for high solar radiation penetration to the plantation floor, creating an ideal environment for the germination and proliferation of various weed species (Sahari *et al.*, 2023) [7]. Weeds compete with young oil palms for essential, limited resources, including nutrients, water, and sunlight. This competition suppresses the vegetative growth rate of oil palms, such as plant height during the first year after planting (Guzzo *et al.*, 2013) [8]. Furthermore, invasive weed species such as *Mikania micrantha* (Bitter vine) do not only compete for resources but also have the potential to release allelopathic compounds that inhibit the root system development of the main crop, as well as serve as alternative hosts for pests and pathogens (Clements & Kato-Noguchi, 2025) [9]. The cumulative impact of this competition is a decline in plant vigor, which has serious implications for productivity; Woittiez *et al.* (2017) [10] reported that yield losses due to weed interference can exceed 50% of optimal production potential, making it a primary hindrance to successful oil palm cultivation.

Considering the negative impacts, weed control during the immature phase is a crucial investment to ensure long-term productivity. Several control methods have been implemented, such as manual weeding and mechanical control. However, the vast scale of oil palm plantations imposes limitations on these methods, including high labor requirements, substantial operational costs, and prolonged execution times, rendering them impractical and less effective (Abbas *et al.*, 2018) [11]. Chemical control using herbicides has become the dominant practice in modern plantations due to its superior effectiveness, cost and time efficiency, and applicability over large areas within short durations. The success of this method is highly dependent on the selection of herbicide type, dosage, timing, and appropriate application techniques (Singh *et al*., 2014) [12].

The application of herbicides containing two or more active ingredients is an increasingly common strategy employed to broaden the control spectrum and enhance efficacy. A mixture formulation of Isopropylamine (IPA) Glyphosate and 2,4-D Dimethylamine represents a combination that offers a comprehensive weed control solution (Andini *et al*., 2022) [13]. Glyphosate is a non-selective systemic herbicide that functions by inhibiting the 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase enzyme in the aromatic amino acid biosynthesis pathway, making it highly effective in controlling weeds from the grass family (Gramineae) and certain broadleaf weeds such as *Ageratum conyzoides* (Billygoat weed) and *Borreria alata* (Broadleaf buttonweed) (Steinrücken & Amrhein, 1980; Kurniadie *et al*., 2022) [14, 15]. In contrast, 2,4-D is a hormonal systemic herbicide (synthetic auxin) that is highly effective in controlling broadleaf weeds by inducing uncontrolled cell growth (Peterson *et al*., 2016) [16]. The combination of these two active ingredients is expected to produce a synergistic effect, significantly broadening the weed control spectrum, accelerating herbicidal action, and potentially suppressing the emergence of resistant weed populations (Umiyati, 2005; Kurniadie *et al*., 2019) [17, 18].

Although this mixture formulation offers significant potential, its field success relies heavily on one critical factor: the determination of an application dose that is both precise and safe for the main crop. Research regarding the optimal dosage of the specific formulation of IPA Glyphosate 350 g/L + 2,4-D Dimethylamine 150 g/L under immature oil palm conditions in Indonesia remains very limited. The use of sub-optimal doses results in incomplete control, while excessive doses are not only economically inefficient but also pose a high risk of causing phytotoxicity to the susceptible young oil palms and potentially leaving environmental residues (Alfandi & Ikhsan, 2021) [19]. It is necessary to conduct research to evaluate the effects of various dosage levels of the IPA Glyphosate and 2,4-D Dimethylamine mixture to determine the optimal dose for suppressing weed growth without inducing phytotoxic effects on the growth of oil palm during the immature phase.

Materials and methods

Field trials were executed between April and August 2025 at an oil palm estate located in Pakenjeng District, Garut Regency, West Java. The study utilized a Randomized Block Design (RBD), incorporating seven distinct treatments replicated four times. The experimental treatments involved applying a herbicide mixture of Isopropyl Amine (IPA) Glyphosate (350 g/L) and 2,4-D Dimethyl Amine (150 g/L) at five different dosage levels: 1.50, 2.25, 3.00, 3.75, and 4.50 L/ha. These were compared against manual weeding and an unweeded control group. Statistical analysis was performed using Analysis of Variance (ANOVA), with significant findings subjected to further mean difference testing at a 95% confidence level.

The study focused on the following response variables:

Initial Vegetation Analysis

Prior to treatment, vegetation composition was assessed via the Sum Dominance Ratio (SDR) technique. This involved deploying 0.5 m × 0.5 m quadrats randomly across the cultivation area to record weed dry weight, density, and frequency. Vegetation within each quadrat was harvested at ground level and segregated by species. Subsequently, samples were oven-dried at 80°C for 48 hours to achieve constant weight. These samples were then used to measure dry mass, calculate population density, and determine frequency based on species presence across quadrats.

Weed observations

Weed data were collected from two 0.5 m × 0.5 m quadrats placed systematically within each treatment plot. Assessments of biomass and total weed population took place at 4, 8, and 12 Weeks After Application (WAA). During sampling, weeds were cut at the soil surface, sorted by species, and dried at 80°C for 48 hours (or until weight constancy was reached) prior to weighing.

Phytotoxicity

Visual evaluations of crop injury were conducted at 4, 8, and 12 WAA using a 0–4 scoring scale. A score of 0 denoted no injury (<5% deviation in leaf morphology, color, or growth), while scores of 1, 2, 3, and 4 corresponded to mild (5–20%), moderate (20–50%), severe (50–75%), and very severe toxicity (>75% damage), respectively.

Result and discussion

Weed Vegetation Analysis

The vegetation analysis revealed a diverse weed flora in the immature oil palm plantation, with *Strachytapheta jamaicensis* exhibiting the highest Sum Dominance Ratio (SDR) at 26.60%, followed by *Miconia crenata* (15.79%) and *Cyperus rotundus* (11.36%) (Table 1). According to established ecological criteria, species with SDR values exceeding 20% are classified as highly dominant and represent the most ecologically important taxa within a plant community (Sumekar *et al*., 2018) [20]. The SDR value of *S. jamaicensis* (26.60%) clearly positions it as the primary dominant species, while *M. crenata* and *C. rotundus*, with SDR values between 10-20%, are categorized as moderately dominant species (Tampubolon *et al*., 2022) [21]. The remaining seven species, each with SDR values below 10%, constitute minor components of the weed community. This dominance hierarchy reflects the competitive ability and ecological adaptation of these species to the environmental conditions of young oil palm plantations.

Tabel 1: Summed Dominance Ratio (SDR)

Weed Nmae	Group	SDR(%)
Strachytapheta jamaicensis	Broadleaf	26,60
Miconia crenata	Broadleaf	15,79
Cyperus rotundus	Sedge	11,36
Pueraria montana	Broadleaf	11,14
Oplismenus compositus	Broadleaf	10,22
Synedrella nodiflora	Broadleaf	6,74
Urena lobata	Broadleaf	5,03
Mitracarpus hirtus	Broadleaf	4,43
Chromolaena odorata	Broadleaf	4,38
Dichanthelium clandestinum	Grass	4,27

The predominance of broadleaf species, comprising 90% of the observed vegetation, aligns with typical weed composition patterns in young oil palm plantations where incomplete canopy closure facilitates broadleaf weed establishment (Sahari *et al*., 2023) [7]. *Strachytapheta jamaicensis*, commonly known as blue porterweed, has been documented as a problematic weed in tropical plantation systems due to its aggressive growth habit and competitive ability. Its classification as a highly dominant species (SDR >20%) indicates that it exerts the greatest competitive pressure on the main crop and should be prioritized in weed management programs (Travlos *et al*., 2018) [22]. Similarly, *Cyperus rotundus*, recognized as one of the world's most noxious weeds, presents significant challenges in perennial crop systems due to its extensive tuber network and rapid regeneration capacity (Peerzada, 2017) [23].

The dominance of these species indicates substantial competitive pressure on young oil palms, as weed interference during the immature phase can reduce nutrient availability, limit light penetration, and suppress vegetative growth (Woittiez *et al*., 2017) [10]. Studies by Ogoudjobi *et al*. (2025) [24] identified comparable weed diversity in oil palm plantations, emphasizing the necessity for effective weed management strategies during early establishment phases. The concentration of dominance within three primary species (*S. jamaicensis*, *M. crenata*, and *C. rotundus*), which collectively account for 53.75% of the total SDR, suggests that herbicide efficacy against these target species will largely determine the overall success of chemical weed control in this plantation system (Yenni *et al*., 2025) [25]. The SDR values obtained in this study provide baseline information essential for evaluating herbicide efficacy against the dominant weed species and for designing targeted management strategies.

Average Dry Weight of Weeds

Dry Weight of *Strachytapheta jamaicensis*

The herbicide mixture demonstrated substantial efficacy in suppressing *Strachytapheta jamaicensis* biomass across all observation periods (Table 2). At 4 weeks after application (WAA), all herbicide treatments achieved near-complete control (0.00-0.15 g dry weight) compared to the untreated control (4.36 g), representing a >96% reduction. By 12 WAA, treatments B (2.25 L/ha), D (3.75 L/ha), and E (4.50 L/ha) maintained superior control with dry weights of 0.28 g, 0.00 g, and 0.00 g, respectively, compared to the control (21.53 g).

S. jamaicensis is frequently characterized as a recalcitrant species with allelopathic properties, often exhibiting tolerance to glyphosate monoproducts (Solikin, 2016) [26]. Sumekar *et al*. (2024) [27] reported the inefficacy of standalone glyphosate applications against this species. The superior control observed in the present study suggests a synergistic interaction, where the inclusion of 2,4-D likely enhanced herbicide uptake or translocation within the broadleaf tissues. This aligns with Palma-Bautista *et al*. (2021) [28], who demonstrated that the addition of synthetic auxins (such as 2,4-D) significantly improves the control of glyphosate-tolerant broadleaf weeds.

Tabel 2: Average Dry Weight of *Strachytapheta jamaicensis*

Code	Treatment	Dosage (l/ha)	Average Weight of Weeds		
			4WAA	8 WAA	12 WAA
A	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	1,50	0,00 a	3,06 a	5,28 ab
B	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/L	2,25	0,00 a	0,00 a	0,28 a
C	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,00	0,00 a	1,92 a	1,81 ab
D	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,75	0,08 a	0,21 a	0,00 a
E	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	4,50	0,15 a	0,00 a	0,00 a
F	Manual Weeding	-	0,95 a	3,08 a	9,68 bc
G	Control	-	4,36 b	11,28 b	21,53 c

Manual weeding (Treatment F) demonstrated inferior long-term control, with weed regrowth reaching 9.68 g at 12 WAA, highlighting the limitations of mechanical control methods for perennial weed species. The rapid regrowth following manual weeding corroborates findings by Hussain *et al*. (2018) [29], who reported that mechanical weeding alone provides only temporary suppression without addressing underground reproductive structures.

Dry Weight of *Miconia crenata*

Miconia crenata exhibited pronounced vulnerability to the herbicide mixture, with Treatments B through E achieving total control (0.00 g dry weight) across all observation periods (Table 3). Even the lowest dosage (Treatment A, 1.50 L ha^{-1}) maintained effective suppression, with dry weights not exceeding 0.27 g throughout the study, representing a >98% reduction compared to the control (17.71 g at 12 WAA).

The enhanced efficacy against *M. crenata* is likely attributable to its sensitivity to auxinic herbicides, which are particularly potent against woody and semi-woody broadleaf species (Todd *et al*., 2020) [30]. The systemic nature of both glyphosate and 2,4-D facilitates translocation throughout the plant, ensuring the destruction of both above-ground and subterranean tissues (Duke, 2018) [31]. Research by Wibawa *et al*. (2009) [32] indicates that herbicide mixtures containing glyphosate provide superior control of broadleaf weeds and grasses in tropical plantation crops compared to single active ingredient applications.

Tabel 3: Average Dry Weight of *Miconia crenata*

Code	Treatment	Dosage (l/ha)	Average Weight of Weeds		
			4WAA	8 WAA	12 WAA
A	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	1,50	0,04 a	0,12 a	0,27 a
B	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	2,25	0,00 a	0,00 a	0,00 a
C	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,00	0,00 a	0,00 a	0,00 a
D	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,75	0,00 a	0,00 a	0,00 a
E	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	4,50	0,00 a	0,00 a	0,00 a
F	Manual Weeding	-	0,69 ab	0,55 a	1,95 a
G	Control	-	2,07 b	7,50 b	17,71 b

The significant disparity between herbicide treatments and manual weeding (Treatment F), which resulted in a biomass of 1.95 g at 12 WAA, underscores the value of chemical control for species like *M. crenata* that readily regenerate from stem fragments (Norsworthy *et al*., 2012) [33].

Dry Weight of *Cyperus rotundus*

The control of *Cyperus rotundus* proved to be more challenging than that of broadleaf species, reflecting the inherent difficulty in managing this recalcitrant sedge (Table 4). Nevertheless, Treatments D (3.75 L ha⁻¹) and E (4.50 L ha⁻¹) achieved complete control (0.00 g) throughout the observation period, whereas lower dosages exhibited variable efficacy. Treatment A (1.50 L ha⁻¹) demonstrated inadequate control at 12 WAA (0.75 g), indicating a clear dose-response relationship for *C. rotundus* suppression.

The moderate efficacy of glyphosate against *C. rotundus* aligns with the well-documented challenges in controlling this species (Travlos *et al*., 2020; Perreira *et al*., 1987; Webster *et al*., 2008) [34, 35, 36]. The complex tuber system of *C. rotundus* confers significant herbicide tolerance, necessitating sufficient translocation to the underground storage organs for effective control (Bariuan *et al*., 1999) [37]. A study by Le and Morell (2021) [38] reported that glyphosate applied at 480 g a.i. ha⁻¹ provided only moderate control of purple nutsedge, mirroring the results observed with the lower dosages in this study.

The inclusion of 2,4-D dimethylamine in the mixture may have contributed to the enhanced control observed at higher rates. Although 2,4-D alone typically exhibits limited efficacy on sedges, its combined application with glyphosate has been shown to improve translocation and compromise tuber viability (Nath *et al*., 2025) [39]. However, Chase and Appleby (1979) [40] noted that environmental conditions, particularly soil moisture and relative humidity, significantly influence glyphosate efficacy on *C. rotundus*, which may account for the variable performance observed at intermediate dosages.

Tabel 4: Average Dry Weight of *Cyperus rotundus*

Code	Treatment	Dosage (l/ha)	Average Weight of Weeds		
			4WAA	8 MSA	12 MSA
A	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	1,50	0,05 a	0,19 a	0,75 a
B	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/L	2,25	0,10 a	0,55 a	0,19 a
C	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,00	0,02 a	0,00 a	0,05 a
D	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,75	0,00 a	0,00 a	0,00 a
E	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	4,50	0,00 a	0,00 a	0,00 a
F	Manual Weeding	-	0,06 a	1,17 ab	0,24 a
G	Control	-	0,30 b	3,42 b	2,07 b

Manual weeding demonstrated minimal impact on *C. rotundus* populations (0.24 g at 12 WAA vs. 2.07 g in the control), underscoring the failure of mechanical control to address the extensive network of tubers that facilitates rapid regrowth (Doll & Piedrahita, 1982; Kumar *et al*., 2012) [41, 42].

Phytotoxicity

No phytotoxic symptoms were observed in the immature oil palm across all treatments throughout the 12-week observation period (Table 5), with every treatment registering a score of 0 on the phytotoxicity scale. This absence of crop injury confirms the selectivity and safety of the IPA glyphosate + 2,4-D dimethylamine mixture when applied as a directed spray in immature oil palm plantations.

Tabel 5: Phytotoxicity

Code	Treatment	Dosage (l/ha)	Phytotoxicity		
			4WAA	8 WAA	12 WAA
A	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	1,50	0,00 a	0,00 a	0,00 a
B	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/L	2,25	0,00 a	0,00 a	0,00 a
C	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,00	0,00 a	0,00 a	0,00 a
D	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	3,75	0,00 a	0,00 a	0,00 a
E	IPA Glyphosate 350 g/l + 2,4-D Dimethyl Amine 150 g/l	4,50	0,00 a	0,00 a	0,00 a
F	Manual Weeding	-	0,00 a	0,00 a	0,00 a
G	Control	-	0,00 a	0.00 a	0,00 a

The safety profile observed in this study aligns with previous research indicating that glyphosate and 2,4-D do not induce phytotoxic responses in crops when applied using appropriate techniques that avoid direct contact with foliage (Ofusu-budu *et al*., 2014; Traore *et al*., 2010; Yang Zu, 1978) [43, 44, 45]. Wibawa *et al*. (2009) [32] reported no adverse effects on the vegetative growth of two-year-old oil palms treated with glyphosate at rates up to 1600 g a.i. ha⁻¹, provided that spray drift was prevented from contacting the fronds. Similarly, Wong (1981) [46] found that young oil palms exhibited tolerance to glyphosate when the herbicide was applied to the weed canopy within the palm circles.

The selectivity of both active ingredients contributes to the observed safety. Glyphosate targets the shikimate pathway, which, although present in all plants, exhibits variable susceptibility depending on the application method and level of exposure (Shaner, 2009) [47]. In oil palm management, directed spraying onto the weed layer minimizes herbicide contact with palm tissues. The 2,4-D component, while potentially hazardous to dicotyledonous crops, has a minimal impact on oil palm (a monocot) when applied at recommended dosages (Akobundu, 1987) [48].

The absence of phytotoxicity even at the highest dosage (4.50 L ha⁻¹) provides a significant safety margin for field applications under varying environmental conditions. These findings stand in contrast to reports of herbicide damage in other plantation crops, where misapplication or excessive dosages have led to growth abnormalities (Price *et al*., 2011) [49].

Conclusion

This field trial demonstrates that the herbicide mixture of Isopropylamine Glyphosate (350 g/L) and 2,4-D Dimethylamine (150 g/L) provides highly effective control of dominant weed species in immature oil palm plantations without inducing phytotoxicity to the crop. The herbicide mixture achieved superior control of *Strachytapheta jamaicensis* and *Miconia crenata* across all application rates (1.50-4.50 L/ha), with over 96% biomass reduction compared to the untreated control. The application rates of 2.25, 3.75, and 4.50 L/ha maintained excellent suppression of *S. jamaicensis* throughout the 12-week observation period. Complete control of *M. crenata* was achieved at rates ≥2.25 L/ha, demonstrating the species' high susceptibility to the herbicide combination.

Control of *Cyperus rotundus*, a notoriously difficult sedge species, exhibited a clear dose-response relationship, with complete suppression achieved only at the higher rates of 3.75 and 4.50 L/ha. Critically, no phytotoxic symptoms were observed on immature oil palms at any application rate, confirming the safety and selectivity of directed herbicide applications in young plantations. Manual weeding proved inferior to chemical control, particularly for perennial species with extensive underground reproductive structures.

Based on the comprehensive efficacy profile and safety margin observed, the application rate of 3.75 L/ha is recommended as the optimal dose for immature oil palm plantations. This rate ensures complete control of all dominant weed species, including the recalcitrant *C. rotundus*, while maintaining crop safety and providing economic efficiency. The findings provide plantation managers with evidence-based dosage recommendations for implementing effective and sustainable weed management programs during the critical immature phase of oil palm cultivation.

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