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Influence of S-Metolachlor and Nicosulfuron on Weed Flora, Density, and Yield Performance of Maize

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ABSTRACT

Maize production in areas with heavy weed infestation depends largely on effective weed control. Therefore, field trials were conducted during 2021 and 2022 wet seasons at the Irewumi community in Ilorin West Local Government Area of Kwara State to examine the effects of S-metolachlor and nicosulfuron on weed population characteristics and maize performance. The study evaluated changes in weed species composition, weed density, weed suppression efficiency, and growth and yield parameters of maize. The experiment followed a randomized complete block design consisting of six treatment options replicated four times. These treatments included a weed-free plot, two application rates of S-metolachlor (3 and 6 L ha⁻¹), two rates of nicosulfuron (1.5 and 3 L ha⁻¹), and an untreated weedy control. Observations and measurements were taken on weed flora, weed density, weed control efficiency, and maize yield components. Findings revealed that plots treated with herbicides showed markedly lower weed density and improved weed control efficiency compared to the untreated plots. Among all treatments, nicosulfuron applied at 1.5 L ha⁻¹ produced the most effective weed suppression, followed closely by S-metolachlor at 3 L ha⁻¹. These treatments also resulted in superior maize yield performance. Based on the outcomes of the study, it was concluded that applying nicosulfuron at 1.5 L ha⁻¹ or S-metolachlor at 3 L ha⁻¹ provides effective weed control and enhances maize grain yield under the environmental conditions of the study area. The use of these herbicide rates is therefore recommended for maize production in similar agro-ecological zones.

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1.0 Introduction

Maize (*Zea mays* L.) is a cereal crop belonging to the family Poaceae and is widely cultivated across the world because of its economic importance, nutritional value, and diverse industrial uses. It is a major staple food and an important source of energy for millions of people, thereby contributing significantly to global food security [1]. Over time, maize has transitioned from being primarily a subsistence crop to a commercially valuable commodity, supplying raw materials for numerous agro-based industries [2].

In Nigeria, maize production has shown considerable variation in recent years. National output increased from approximately 12.4 million metric tons in 2020 to about 12.75 million metric tons in 2021 [3]. However, estimates for 2023 indicate a decline to roughly 10.8 million metric tons, which represents only a slight increase over 2022 levels and remains below the 2021 peak [4]. This inconsistency in production shows persistent constraints to sustained maize yield improvement, including declining soil fertility, pest infestation, and inappropriate agronomic practices [5], as well as intense weed competition [5]. Among these factors, weed infestation is one of the most severe abiotic stresses affecting maize production. Weeds compete with maize for essential growth resources such as light, nutrients, soil moisture, and carbon dioxide, often causing yield losses ranging from 60 to 80 percent under heavy infestations [6; 7].

Several weed management strategies, such as mechanical, cultural, biological, and chemical control methods are employed in maize production systems [8]. However, mechanical and cultural practices are labor-intensive and often ineffective under high weed pressure, while biological control methods are generally slow and unreliable. These limitations have increased dependence on chemical weed control as a more efficient and timely approach to weed suppression in maize fields [8]. Among the herbicides commonly available in Nigeria, S-metolachlor and nicosulfuron are widely used [8]. S-metolachlor is a selective pre-emergence herbicide that primarily controls annual grasses and some broadleaf weeds, whereas nicosulfuron is a selective post-emergence herbicide effective against a wide range of grass and broadleaf weed species [9]. Despite their effectiveness, prolonged and repeated herbicide use result in challenges such as changes in weed species composition, reduced weed control efficiency, and the emergence of herbicide-resistant weed biotypes [10]. In addition, limited information is available on the effects of S-metolachlor and nicosulfuron on the morphophysiological characteristics and yield attributes of maize under Nigerian agro-ecological conditions.

Therefore, the present study was conducted to assess the effects of S-metolachlor and nicosulfuron on weed species composition, weed density, and maize yield performance.

2.0 Materials and Method

2.1 Study Site

The field trial was carried out during the 2021 and 2022 cropping seasons at Irewumi Community in Ilorin West Local Government Area of Kwara State, Nigeria. The study location lies between latitudes 8°31.3651 N and 8°52.68031 N and longitudes 4°31.4061 E and 4°52.79301 E. The area is situated within the southern Guinea savanna agro-ecological zone. Climatic conditions of the site include average monthly rainfall ranging from 10.34 to 38.57 mm, mean annual temperatures between 22 and 33 °C, and relative humidity values of approximately 78.93 to 85.88 percent.

2.2 Herbicide Application Timing, Growth Stage, and Method

Weed control was achieved through the sequential use of pre- and post-emergence herbicides. S-metolachlor was applied soon after sowing, prior to the emergence of maize and weed seedlings, while nicosulfuron was applied later in the season when maize had developed 3–5 leaves and weeds were at an early growth stage.

Herbicide application was performed using a knapsack sprayer fitted with an appropriate nozzle. The sprayer was operated to cover a swath width of about 1.5 m, with the spray nozzle positioned approximately 30 cm above the soil surface to ensure uniform application.

2.3 Experimental Design and Treatment Details

The experiment was established using a Randomized Complete Block Design with six treatment combinations replicated four times. Each net plot measured 3 m², with a spacing of 1 m between plots to minimize treatment interference. Every plot consisted of six uniformly constructed ridges suitable for maize production. The treatments applied were as follows: T0 represented the weed-free control, T1 involved the application of S-metolachlor at 3 L ha^{-1}, T2 consisted of S-metolachlor at 6 L ha^{-1}, T3 was treated with nicosulfuron at 1.5 L ha^{-1}, T4 received nicosulfuron at 3 L ha^{-1}, and T5 served as the untreated weedy check.

2.4 Planting and Cultural Practices

Certified seeds of an early maturing, Striga-resistant maize variety, SUWAM-1-SR-Y, were obtained from the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. Sowing was carried out by placing three seeds per planting hole at a depth ranging from 2.5 to 5 cm, with an inter-row spacing of 75 cm and an intra-row spacing of 25 cm. Seedlings were later thinned to two plants per stand after successful establishment. All recommended agronomic practices, including fertilizer application and field maintenance, were uniformly applied across all treatments until crop maturity.

2.5 Soil Sampling and Laboratory Analyses

Soil samples were collected from a depth of 0 to 20 cm at three randomly selected locations within each subplot prior to planting. Both undisturbed and disturbed soil samples were obtained. Undisturbed samples were collected using cylindrical metal core samplers with a volume of 100 cm³, while loose soil samples from each plot were bulked to form composite samples. The composite samples were air-dried to a constant weight, gently crushed, and passed through a 2 mm sieve to prepare them for laboratory determination of selected soil physicochemical properties.

2.6 Analysis of Soil Physicochemical Properties

Soil pH was measured in distilled water and in 1 M potassium chloride solution using a soil-to-solution ratio of 1:2.5 with a calibrated pH meter fitted with a glass electrode, following standard procedures [11]. Organic carbon content was determined using the modified Walkley-Black wet oxidation method [12], and soil organic matter was estimated by multiplying the organic carbon value by a factor of 1.724. Available phosphorus was extracted using Bray II solution and quantified through a colorimetric procedure as described by [13]. Exchangeable bases, exchangeable acidity, and apparent cation exchange capacity were determined using ammonium acetate extraction in accordance with established methods [14]. Effective cation exchange capacity was calculated as the sum of exchangeable bases and exchangeable acidity.

2.7 Data Collection

The relative abundance of weed species across all treatments for each experimental year was expressed as a percentage and calculated following the method described by [15] using the formula:

$$\text{Relative Abundance (RB)} = \frac{Abundance\ of\ individual\ weed\ specie}{Total\ number\ of\ all\ the\ species} x\ 100$$

Weed density for individual weed species was assessed at 3, 6, 9, and 12 weeks after planting by sampling three randomly selected points within each plot. At each sampling point, weeds were counted within a quadrat measuring 0.25 m². Weed density was computed following the method described by [16] using the formula:

$$\text{Weed density} = \frac{Average\ number\ of\ weed\ species}{Net\ area\ of\ quadrat}$$

Weed control efficiency was determined based on weed dry matter using the formula proposed by [17] and adopted by [18]. Weed control efficiency was calculated as:

$$\text{Weed control efficiency} = \frac{Weed\ dry\ weight\ of\ the\ unweeded\ control - Weed\ dry\ weight\ of\ the\ treatment}{Weed\ dry\ weight\ of\ the\ unweeded\ control} x\ 100$$

Ear length was measured from ten randomly selected maize ears from each net plot. Measurements were taken from the base of the ear to the tip using a meter rule, and the mean value was recorded. Cob diameter was determined from the same ten ears using a thread to obtain the circumference, which was then measured in centimeters with a meter rule, and the average value was calculated. The number of kernels per row was obtained by counting kernels on ten sampled ears per plot, and the mean value was recorded. Kernel rows per ear were determined by counting the total number of rows on each of the ten sampled ears from each plot, after which the average was computed. Seed weight was estimated by randomly selecting kernels from the bulked grains obtained from the ten sampled plants per treatment plot. One hundred kernels were counted and weighed using an electronic top loading balance to obtain the 100 seed weight [19].

Grain yield per plot was determined by shelling all cobs harvested from each net plot and weighing the grains using a sensitive electronic top loading balance (MP 1001, A and D Company, Japan).

All collected data were subjected to statistical analysis using the Statistical Package for Social Sciences version 22.0. Data for each year were analyzed separately. One way analysis of variance was applied to evaluate treatment effects at different crop growth stages. Statistical significance was assessed at a probability level of $p < 0.05$. Treatment means were separated using Duncan Multiple Range Test.

3.0 Results and Discussion

3.1 Physical and chemical properties of soil used in the experimental site

The physical and chemical properties of the surface soil sampled at a depth of 0 to 20 cm are presented in Table 1. The soil of the experimental site was classified as sandy loam in texture. Additional physicochemical characteristics of the soil at the study location are also summarized in the table.

3.2 Weed Flora Composition and Relative Abundance

During the 2021 and 2022 cropping seasons, a total of 12 and 15 weed species, respectively, representing six botanical families, were identified within the experimental plots as presented in Table 2. The family Asteraceae recorded the highest number of species with five representatives, followed by Poaceae with four species. In contrast, Amaranthaceae, Malvaceae, Portulacaceae, and Cyperaceae were represented by fewer species. In terms of relative abundance, species belonging to the family Asteraceae were the most prevalent across the experimental site, followed by Euphorbiaceae, while Cyperaceae and Amaranthaceae recorded the lowest abundance during the 2021 and 2022 seasons, respectively. The presence of diverse weed species indicates a heterogeneous weed community within the study area. The predominance of broadleaf weed species may be associated with favorable environmental conditions such as adequate soil moisture, moderate temperature regimes, and sufficient light intensity, which enhance their establishment and growth [20]. Also, soils with adequate nutrient availability, suitable pH levels, and good moisture holding capacity are often more conducive to the proliferation of broadleaf weeds than grasses [21].

Table 1: Physico-chemical properties of soil used in the experimental site

Chemical properties	2021	2022
pH	7.80	7.65
Exchangeable acidity (cmol)	1.72	1.67
Electrical conductivity (dsm^{-1})	1.7	1.73
Moisture (%)	1.06	1.18
OC (%)	2.31	2.33
Total N ($g\ kg^{-1}$)	2.4	2.46
Av. P (mg/kg)	3.68	3.87
Ca (cmol)	4.50	4.50
Mg (cmol)	1.32	1.16
Na (cmol)	1.70	1.73
K^{+} (cmol)	2.0	2.33
Sand (%)	86.2	84.26
Clay (%)	8.98	9.26
Silt (%)	4.82	5.48
Textural class	Sandy loam	Sandy loam

Table 2: Weed Species Encountered on the Experimental Site with their Relative Abundance

S/N	Weed species		Relative abundance (%)		
		Family	2021	2022	LC/M
1	*Tridax procumbens*	Asteraceae	4.16	1.6	ABL
2	*Biden pilosa*	Asteraceae	-	4.22	ABL
3	*Chromolaena odorata*	Asteraceae	39.87	26.43	PBL
4	*Aspilia Africana*	Asteraceae	0.34	8.22	PBL
5	*Ageratum conyzoides*	Asteraceae	0.36	2.06	PBL
6	*Panicum maximum*	Poaceae	6.36	12.22	PG
7	*Imperata cylindrical*	Poaceae	5.16	3.12	PG
8	*Andropogon tectorum*	Poaceae	-	0.54	PBL
9	*Eleusine indica*	Poaceae	5.16	3.20	AG
10	*Phyllantrus amarus*	Euphorbiaceae	20.12	17.25	AG
11	*Euphorbia heterophyla*	Euphorbiaceae	12.16	14.2	ABL
12	*Sida acuta*	Malvaceae	3.12	1.32	PBL
13	*Cyperus difformis*	Cyperaceae	-	3.20	AS
14	*Talinium triangulare*	Portulacaceae	2.16	2.36	PBL
15	*Amaranthus spinosus*	Amarathanceae	1.03	0.06	ABL

N.B: LC/M = Life Cycle/Morphology Group; ABL = Annual Broad Leaf, PBL = Perennial Broad Leaf, PG = Perennial Grass, AG = Annual Grass

3.3 Weed Density

The influence of herbicide treatments on weed density in maize plots during the 2021 and 2022 cropping seasons is presented in Table 3. In general, weed density declined progressively from 3 weeks after treatment to 12 weeks after treatment across most herbicide-treated plots. An exception to this trend was observed in plots treated with S-metolachlor at rates of 3 and 6 L ha⁻¹. Among the treatments evaluated, nicosulfuron applied at 3 L ha⁻¹ recorded the lowest weed density at 12 weeks after treatment, with values of 8.00 and 14.67 in 2021 and 2022, respectively. This was followed by nicosulfuron at 1.5 L ha⁻¹, which resulted in weed density values of 32.00 and 29.34. In contrast, the highest weed density among herbicide-treated plots at 12 weeks after treatment was observed in plots treated with S-metolachlor at 3 L ha⁻¹, with corresponding values of 53.33 and 54.66. Compared with the untreated weedy check, all nicosulfuron treatments significantly reduced weed population. The substantial reduction in weed density following nicosulfuron application may be attributed to its effectiveness in controlling both grass and broadleaf weed species, thereby limiting weed establishment and subsequent proliferation within the plots. The observed reduction in weed population as a result of herbicide application aligns with previous findings reported by [22]. Similarly, [23] documented that post-emergence herbicide application at varying rates in transgenic maize hybrids led to lower weed density and improved weed control efficiency when compared with other weed management approaches.

Table 3: Effects of Herbicide Application on Weed Density of Maize During 2021/2022 Cropping Seasons

Weed Density (plants/m^2)								
	2021				2022			
Weeks after Treatment								
Treatment	3	6	9	12	3	6	9	12
T_0	0.00^f	0.00^f	0.00^f	0.00^f	0.00^f	0.00^f	0.00^f	0.00^f
T_1	48.00^d	40.00^c	42.67^b	53.33^b	41.32^d	34.64^c	46.67^b	54.66^b
T_2	40.00^e	33.33^e	32.00^d	37.33^c	33.32^e	30.64^e	34.66^d	41.33^c
T_3	80.00^b	45.33^b	41.33^c	32.00^d	62.64^c	42.64^b	36.00^c	29.34^d
T_4	69.33^c	34.67^d	29.33^e	8.00^e	74.64^b	32.00^d	22.66^e	14.67^e
T_5	90.67^a	106.67^a	146.67^a	166.67^a	92.00^a	101.33^a	142.64^a	174.67^a

Means sharing the same superscript within a column are not significantly different at $P \leq 0.05$. Treatment codes are as follows: T0 = weed-free control, T1 = 3 L ha⁻¹ S-metolachlor, T2 = 6 L ha⁻¹ S-metolachlor, T3 = 1.5 L ha⁻¹ nicosulfuron, T4 = 3 L ha⁻¹ nicosulfuron, T5 = untreated weedy check.

3.4 Weed Control Efficiency

Herbicide application significantly reduced weed growth in maize plots compared with the untreated weedy check during both cropping seasons, with differences observed at $P \leq 0.05$. All herbicide-treated plots recorded higher weed control efficiency than the weedy check. Among the treatments evaluated, nicosulfuron applied at rates of 3.0 L ha⁻¹ and 1.5 L ha⁻¹ produced the highest weed control efficiency, second only to the weed-free control plot, as presented in Table 4.

A pronounced improvement in weed control efficiency was observed in plots treated with nicosulfuron at 3.0 L ha⁻¹. This response may be attributed to the substantial reduction in weed density and biomass recorded in these plots, which shows the strong suppressive effect of the herbicide on weed growth. Herrbicide treatments were more effective in reducing weed population and dry matter accumulation, thereby producing outcomes comparable to those obtained under weed-free conditions maintained through manual weeding. In contrast, the weedy check plots exhibited poor weed control performance. These results are consistent with earlier findings reported by [24], who observed that herbicide application in maize resulted in superior weed suppression and improved control efficiency compared with untreated control plots.

Table 4: Effect of Herbicide Application on Weed Control Efficiency in Maize Plots During 2021 and 2022 Cropping Seasons

Treatment	Weed Control Efficiency (%) 2021	Weed Control Efficiency (%) 2022
T1	79.44 ± 0.49^{e}	80.60 ± 0.65^{d}
T2	82.98 ± 0.07^{d}	83.50 ± 0.02^{c}
T3	90.00 ± 1.06^{c}	89.80 ± 0.61^{b}
T4	92.54 ± 0.20^{b}	92.51 ± 0.59^{a}
T5	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}

Means sharing the same superscript within a column are not significantly different at P ≤ 0.05. Treatment codes: T1 = 3 L ha^{-1} S-metolachlor, T2 = 6 L ha^{-1} S-metolachlor, T3 = 1.5 L ha^{-1} nicosulfuron, T4 = 3 L ha^{-1} nicosulfuron, T5 = untreated weedy check

3.5 Effects of Herbicide Application on Maize Yield Components and Grain Yield

Application of herbicides significantly improved maize yield components compared with the untreated weedy check plots (Tables 5 and 6). Plots treated with nicosulfuron consistently produced superior values for ear length, ear diameter, number of kernel rows per ear, number of kernels per ear, seed weight per ear, 100-seed weight, and overall grain yield. In contrast, the lowest values for all yield parameters were recorded in the weedy check plots. The observed improvement in yield components in herbicide-treated plots can be attributed to the reduction in weed density and dry matter accumulation, which reduces competition for essential resources such as nutrients, light, and water. This reduction in weed pressure allows maize plants to allocate more resources toward reproductive development, resulting in enhanced yield traits and higher grain yield [25]. These findings are consistent with the results reported by [26], which demonstrated that effective weed management significantly suppresses weed growth, thereby enhancing maize grain yield and optimizing yield components. The markedly lower grain yield observed in the weedy check plots is likely a consequence of high weed density, which limits maize growth and development through intense competition for soil nutrients, water, and light [27; 28]. This outcome supports the findings of [29], who reported that prolonged weed interference reduces cob number per plant, highlighting the negative impact of extended competition between weeds and maize on crop productivity.

Table 5: Effects of S-metolachlor and Nicosulfuron on the yield components and yield of maize in the 2021 cropping season

Treatment	Ear length (cm)	Ear Diameter (cm)	Rows of kernel/ear	No of kernel/ear	Weight of seed/ear (g)	100 seed weight (g)	Grain yield/plot (kg)	Grain yield /hectare (kg)
T_0	18.12±2.13^{a}	5.01±0.01^{c}	15.25±0.49^{ab}	384.00±2.31^{d}	105.00±0.00^{c}	19.20±0.45^{c}	1.76±0.21^{d}	1.96±0.12^{d}
T_1	18.20±2.21^{a}	5.05±0.02^{c}	15.95±0.10^{ab}	386.38±1.05^{c}	112.13±1.08^{b}	19.28±0.42^{bc}	1.89±0.21^{c}	2.10±0.12^{c}
T_2	16.31±1.54^{ab}	5.03±0.03^{c}	15.00±0.58^{b}	376.38±0.94^{e}	95.38±0.48^{d}	19.23±0.54^{c}	1.70±0.21^{e}	1.89±0.11^{e}
T_3	18.38±2.18^{a}	5.38±0.03^{a}	16.38±0.36^{a}	403.75±0.02^{a}	114.00±0.00^{a}	21.09±0.58^{a}	2.08±0.21^{a}	2.31±0.12^{a}
T_4	17.76±2.04^{a}	5.18±0.05^{b}	15.88±0.07^{a}	392.25±0.50^{b}	105.13±0.57^{c}	20.18±0.57^{b}	1.96±0.24^{b}	2.18±0.14^{b}
T_5	13.00±0.69^{b}	4.80±0.07^{d}	12.75±0.20^{c}	293.13±0.59^{f}	89.63±0.91^{e}	17.29±0.47^{d}	1.30±0.21^{f}	1.44±0.12^{f}
Total Mean	16.96±0.60	5.07±0.04	15.20±0.30	372.65±8.86	103.55±2.10	19.38±0.30	1.78±0.26	1.99±67.07

Means with the same superscript across the column are not significantly different at P ≤ 0.05 T_0= control (weed free); T_1=3 L/ha. of S-metolachlor; T_2= 6 L/ha. of S-metolachlor; T_3 = 1.5L / ha of Nicosulfuron; T_4= 3 l/ ha of Nicosulfuron; T_5= weedy check.

Table 6: Effects of S-metolachlor and Nicosulfuron on the yield components and yield of maize in the 2022 cropping season

Treatment	Ear length (cm)	Ear Diameter (cm)	Rows of kernel/ear	No of kernel/ear	Weight of seed/ear (g)	100 seed weight (g)	Grain yield/plot (kg)	Grain yield /hectare (kg)
T_0	18.78±0.33^{ab}	5.18±0.09^{a}	15.30±0.30^{b}	383.33±2.40^{c}	108.23±1.11^{b}	19.63±0.32^{b}	1.79±0.23^{c}	1.98±0.13^{d}
T_1	18.98±0.39^{ab}	5.34±0.22^{a}	15.92±0.13^{ab}	383.00±1.52^{c}	119.57±0.72^{a}	19.35±0.18^{bc}	1.89±0.21^{bc}	2.10±0.12^{c}
T_2	17.18±0.46^{c}	5.24±0.14^{a}	15.17±0.44^{b}	381.00±4.04^{c}	98.40±0.30^{c}	19.45±0.25^{bc}	1.74±0.24^{d}	1.93±0.14^{e}
T_3	19.23±0.44^{a}	5.40±0.04^{a}	16.37±0.32^{a}	406.00±1.15^{a}	119.00±0.58^{a}	22.29±0.16^{a}	2.11±0.24^{a}	2.34±0.14^{a}
T_4	17.72±0.26^{bc}	5.23±0.02^{a}	15.96±0.04^{ab}	396.00±1.20^{b}	109.33±0.66^{b}	21.84±0.93^{a}	1.99±0.26^{ab}	2.21±0.15^{b}
T_5	15.63±0.68^{d}	4.61±0.30^{b}	12.80±0.21^{c}	293.67±4.33^{d}	87.30±0.35^{d}	18.17±0.12^{c}	1.35±0.24^{e}	1.50±0.14^{f}
Total Mean	17.92±0.34	5.16±0.09	15.25±0.30	373.83±9.00	106.97±2.76	20.12±0.38	1.81±0.26	2.01±64.68

Means with the same superscript across the column are not significantly different at P ≤ 0.05 T_0= control (weed free); T_1= 3 L/ha. of S-metolachlor; T_2= 6 L/ha. of S-metolachlor; T_3 = 1.5L / ha of Nicosulfuron; T_4= 3 l/ ha of Nicosulfuron; T_5= weedy check.

4.0 Conclusion

Application of S-metolachlor at 3 L ha^{-1} and nicosulfuron at 1.5 L ha^{-1} provided effective weed suppression and significantly improved maize productivity. This herbicide sequence ensures early-season weed control and reduces competition during critical growth stages of maize. Farmers in similar agro-ecological zones can adopt this approach to improve crop establishment, reduce labor costs associated with manual weeding, and achieve higher yields. Timely application at recommended rates is essential for optimum performance. Integrating this strategy with other sustainable practices will further enhance productivity while minimizing environmental risks**.**

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Declaration

Language editing and formatting support for this manuscript were provided with the assistance of Microsoft Copilot under the supervision of the authors. All scientific content, data analysis, interpretation, and conclusions are entirely the work and responsibility of the authors.

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