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Determining the appropriate period of herbicide application in irrigated wheat in Awash Valley, Ethiopia

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Weed infestation is one of the main menaces of irrigated wheat production and productivity in Ethiopia. This experiment was conducted at Amibara and Fentale districts, to determine the appropriate period of herbicide application in irrigated wheat in Awash Valley. A total of ten treatments; 13, 18, 23, 28, 32, 38, 43 and 48 days after sowing along with a weed-free and weedy check were laid out in a Randomized Complete Block Design (RCBD) with three replication. The result revealed that weed density and biomass increased as weed competition periods increased, with the highest weed densities and biomass reported in weedy check in both study locations. The current study found that critical period of weed crop competition in wheat crop irrigated lowland areas were between 18 to 28 days after planting to avoid economic yield loss. Furthermore, weed growth was faster in the hot area and weed attained an economic threshold level earlier than in Ethiopia's highlands. Weed management in irrigated wheat conditions must be at the early seedling wheat crop stage. Future research should focus on evaluating various herbicides against broad leaf and grass weeds.

Key words: Critical-period, weed populations, pallas herbicide, yield loss.

INTRODUCTION

Wheat (*Triticum estivum* L.) is one of the world's most significant cereal crops. The global yearly wheat production is 768.5 million tons from 220.24 million ha, with an average yield of 3.5 tons ha^{-1} (USDA, 2021). In Ethiopia, it is the fourth most prevalent cereal crop after maize, sorghum, and teff. Bread wheat is well-known for being a high-energy and protein source. The average annual production and productivity of wheat in Ethiopia is 3.1 tons per ha (CSA, 2021).

Weed is one of the most important biotic variables that reduce wheat yield and productivity (Abbas et al., 2009; Meulen and Chauhan, 2017). Weeds are unseen enemies of wheat, causing biomass and grain yield losses in wheat crop (Iqbal et al., 2017). Farmers who are aware of the critical period of weed crop competition have a distinct advantage. In rain fed areas of Ethiopia, the critical period of weed competition is 20 to 30 days after sowing, but in Pakistan, the important period of weed competition is 30-60 days after sowing (Sarfaraz et al., 2013; Zewdie, 2019). Crop output is reduced when weed intensity and competition time with crop plants increases (Dalley et al., 2006; Chaudhary et al., 2008). Weed competition reduces crop growth and output during the early phases of growth (Reddy, 2004). Annual losses to

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wheat crops owing to weed infestation are reported to be in the billions; these massive losses justify effective weed management for profitable economic returns. Application of herbicides decreased dry weight of weeds significantly compared to dry weight in non-treated plots and increased yield components and grain yield (Tesfay et al., 2014, Yared et al., 2018).

Weed causes yield reduction in wheat from 10-65% (Habtamu and Genene, 2001). Timely weed control is an important aspect for reducing weed crop competition and increasing crop production and productivity (Zewdie, 2019). Manual method of weed removal is very expensive and increasing cost of labor, draft animals and implements and weeds cannot effectively be managed merely due to crop mimicry, therefore, control weed at critical period with chemical has become necessary (Marwat et al., 2008). In addition to this weeding at proper time herbicide and supplementing with hand weeding could provide favorable environment for the crop which ultimately lead to better grain filling (Amare et al., 2016; Yared et al., 2018). Tesfay et al. (2014) reported post-emergence herbicides and hand weeding at tillering stage reduced the dry weight of weeds as compared to herbicides alone or weedy check. Applying Pallas 45OD at effective stage of weed emergence would significantly affect weed population and improve number of wheat grain development (Yared et al., 2018).

Herbicide action might be selective or nonselective. Pyroxsulam (Pallas 45-OD) herbicide is more effective in wheat and teff against generally problematic annual broad leaf and grass weeds (Zewdie, 2019). Weeds managed with Pallas 45 OD produces the best results when grass weeds are treated at the 2-leaf to 2-tillers stage of growth and before broad leaf weeds reach a height of 2 inches or a diameter of 2 inches. When applied to actively developing weeds, the best control is obtained. Weed control may be compromised when weeds are subjected to drought or severe temperatures.

The weed is already posing a significant danger in irrigated wheat-growing areas in Middle Awash. The majority of weed control recommendations originated from Ethiopia's highlands. However, these recommendations are ineffective in irrigated wheat-growing hotspots. This is because the life span of the wheat crop in hot climates is shorter than in highland wheat crops, hence early weed-crop competition is emphasized in hot areas. In addition, the phytotoxicity effect is greater in hot temperature zones. In general, irrigated hot areas need a different recommendation from highland areas. Therefore, the study was aimed to determine the appropriate period of herbicide application in hot lowland irrigated areas.

MATERIALS AND METHODS

Description of the study area

The field experiment was conducted at Werer Agricultural Research center and outstation on farmer field at Metahara in 2019/2020 production year. Werer Agricultural Research center is located with an altitude of 750 m.a.s.l, the latitude of 9°16°N, and longitude of 40° 9°E in Amibara district, Metahara is located with an altitude of 1122 m.a.s.l, the latitude of 8°0'0" N and 39°0'0" E with Fentale district.

Experimental materials and design

The wheat variety Fentale-2, which is widely adapted and recommended for irrigated conditions, was used for field trials. This variety was seeded in December 2019 during the spring cropping season. The experiment was designed using a randomized complete block design (RCBD) with three replications. The plot size was 3 m × 3 m (9 m^2), row to row distance was 0.3 m, and ridge to ridge distance was 0.6 m. Pallas 45 OD was sprayed at 13, 18, 23, 28, 33, 38, 43, and 48 days after sowing, along with weed-free and weedy control included for comparison. All weed treatments were enumerated from a 1 m^2 quadrate that was placed in three randomly selected locations in each plot. Wheat seed was drilled by hand down the row at a seed rate of 100 kg/ha; DAP and UREA fertilizers were applied following a local practice. DAP was applied at the full rate of 100kg/ha at planting, whereas Urea was applied in a split application, half rate during tillering and the half-rate at booting.

Data collection

Collected data were including a number of effective tillers, plant height, thousand kernel weight, grain yield, weed density and weed biomass. The total number and productive tillers were counted from 10 randomly selected plants in each net plot area at harvest. Plant height was measured from 10 randomly tagged plants in each net plot area from the base to the tip of the spike excluding the awns of the main stem at harvest. The number of grains per spike was determined by randomly taking 10 spikes per plot. A thousand seeds were counted from the bulk of threshed produce from the net plot area and their weight was recorded. Total aboveground dry biomass (t ha^{-1}) was determined by taking the weight of the total harvest from each net plot area. Grain yield (t ha^{-1}) was measured after threshing the harvested wheat crop from each net plot and the yield was adjusted at 12.5% grain moisture content. Harvest index was determined as the ratio of grain yield to aboveground dry biomass of the crop. The harvested weeds were placed into paper bags separately and sundry for 10 days, dry weight was measured with sensitive balance and converted into gm^{-2}. The harvesting index was calculated as the ratio of grain yield to above-ground dry biomass per plot and multiplied by 100 at harvest from the respective treatments.

$$Harvesting\ index = \frac{\text{Grain yield} * 100}{\text{Total above} - \text{ground dry biomass yield}}$$

Yield loss: Was calculated based on the maximum yield obtained from a treatment

Yield loss of wheat (%)= $(1 - \frac{\text{wheat yield of each treatment}}{\text{wheat yield of weed}-\text{free check}}) * 100$

Statistical analysis

Collected data were subjected to analyses of variance using SAS analysis of computer software General leaner model (GLM) procedure. Data were subjected to analysis of variance and mean separation was conducted for significant treatment means using least Significance Differences (LSD) at 5% probability level. Descriptive statistic was used to describe the weed population density and number of tillers per plant.

RESULTS AND DISCUSSION

Major weed flora in wheat crop

The weed flora in the wheat crop differed depending on the study location; major weed species found in the Amibara district were *Boerhaviara erecta*, *Xanthium strumarium*, *Portulaca Oleracea*, *Corchorus trilocularis*, and *Ipomea ariocarpa* among the dicots, and *Cyperus rotundus*, *Eriocloa fatmensis*, and *Sorghum arundianace* among monocots. At Fentale district, pre-dominated broad-leaved weeds species were *Galinsoga parviflor*, *X. strumarium*, *Amaranthus sp*, *Guizotia scabra* while the predominated grassy weeds species were *C. rotundus* and *Sorghum arundianacerum*. More than 50% of the weed floras were different in both studied areas, which could be attributed to environmental factors. According to Anderson and Beck (2007), weed flora varies based on environmental circumstances, irrigation, soil type, cropping sequences, and weed control strategies.

Total weeds density before and after herbicide application

Before herbicide application, the maximum total weed density was recorded on the weedy check (90.8 m^2, 64.3 m^2) in Amibara and Fentale, respectively (Table 1). The minimal weed densities were recorded at a weed competition period of 13 days (15.4m^2, 9.8m^2) in respective districts (Table 1). After herbicide application, there was a significant reduction in weed densities with early herbicide application with a range weed competition period of 18-28 days more effectiveness than late herbicide application with a range weed competition period of 33-48 days in both studied locations (Table 1). This could be linked to better weed control by these herbicides even at later phases of crop growth, resulting in lower weed dry matter production. Weeds are plants which compete for nutrients, space, light, and reducing production and productivity, if the weed population density increased in wheat crop (Alemaw and Agegnehu, 2019). Megersa et al. (2017) observed various weed species were effectively controlled by the application of Pallas 45 OD.

Plant height (cm): In studied vicinities, the maximum plant height (78.8 and 86.4 cm) was recorded in weed-free treatment, which was statistically similar to the competition period of 23 days and 28 days after planting (Table 2). The significant minimum plant height (70.6 and 75.4 cm) was recorded in Amibara and Fentale from weedy check, respectively, which, however, was statistically similar to competition periods of 38, 43, and 48 days after planting. The plant height fell significantly as the competition duration extended; however, the difference between 23 and 28 days after planting was not significant. Greater wheat plant height under weed-free treatment could be attributed to higher available resources in the absence of weeds. In both studied locations, the lowest plant height in the weedy check can be attributed to increased competition and the suppressive influence of weeds. The findings are comparable to those of Ali et al. (2014), who found that increased competition periods resulted in reduced plant height in wheat.

Number of productive tillers: Maximum number of productive tillers was recorded from competition period of 23 days (5.1 and 4.7 per plant) and weed-free plots (5.4 and 4.6 per plant); the minimum numbers of productive tillers were recorded from weedy check (2.5 and 2.4 per plant) in Amibara and Fentale districts, respectively (Table 2).

Spike length (cm): Significantly the highest spike length was recorded from weed-free (8.7 and 9.2 cm) in Amibara and Fentale districts and the lowest spike length (6.8 cm) was recorded in weedy check (Table 2). The spike length was increased significantly with a decrease in the competition period. The result showed that a significantly shortest spike length was recorded in a weedy check in both studied locations (Table 2).

The number of grains per spike: Significantly the maximum number of grains per spike was recorded from weed-free (45.2 and 47.5 grain per spike), the lowest number of grains per spike was recorded from weedy check (33.2 and 33.3 grain per spike) (Table 2). The number of grains per spike was significantly similar in the weed competition period of 18, 23, and 28 days after planting (Table 2).

Thousand seed weight: The maximum thousand seed weight (33.3 and 35.3 g) was recorded from weed-free, whereas the lowest competition period (27.0 and 29.3 g) was recorded from weedy check in Amibara and Fentale districts, respectively (Table 3). The reduction in thousand seed weight was higher on the weedy check in both locations (Table 3).

Grain yield: The findings revealed that the weed competition period has a significant impact on wheat grain production (Table 3). The maximum grain yield (3.5 and 4.3 t/ha) was observed in weed-free time, whereas the minimum grain yield (1.3 and 1.6 t/ha) was obtained in weedy check-in Amibara and Fentale districts, respectively (Table 3). The results showed that applying Pallas 45 OD during 18-28 days after planting resulted in the highest grain production in wheat crop. According to (Ahmad et al, 1993), the greatest grain yield was reported in weed-free,

Table 1. Mean of total weed density before and after Pallas 45 OD application in Amibara and Fentale districts, 2019/2020.

Competition period	Amibara		Fentale	
	Weed density (m^{-2}) Before spray	Weed density (m^{-2}) After spray	Weed density (m^{-2}) Before spray	Weed density (m^{-2}) After spray
weedy-13DAS	15.4^{h}	21.6^{cd}	9.8^{g}	14.9^{cd}
Weedy-18DAS	25.8^{g}	2.7^{e}	16.4^{f}	2.7^{e}
Weedy-23DAS	36.2^{f}	3.3^{e}	24.9^{e}	1.6^{e}
Weedy-28DAS	50.6^{e}	3.9^{e}	35.8^{d}	2.3^{e}
Weedy-33DAS	55.1^{de}	6.8^{de}	40.4^{cd}	8.1^{ed}
Weedy-38DAS	60.7^{cd}	12.4^{cde}	44.2^{bc}	15.8^{cd}
Weedy-43DAS	66.4^{c}	27.2^{bc}	46.8^{b}	20.3^{bc}
Weedy-48DAS	75.6^{b}	39.3^{b}	61.6^{a}	27.9^{b}
Weed free	0.0i	0.0^{e}	0.0^{h}	0.0^{e}
Weedy (check)	90.8^{a}	95.8^{a}	64.3^{a}	71.1^{a}
CV	9.1	15.7	8.9	19.4
LSD	***	***	***	**

Source: Field experiment year of 2019/2020

Table 2. Effect of Pallas 45 OD application on yield attributing traits in Amibara and Fentale districts, 2019/2020.

Competition period	Amibara				Fentale			
	PT	PH	SL	NGPS	PT	PH	SL	NGPS
weedy-13DAS	4.7^{abc}	73.4^{cde}	7.4^{cb}	37.8^{ab}	3.7^{b}	81.5^{bc}	7.9^{cd}	38.4^{bc}
Weedy-18DAS	4.5^{cd}	73.5^{cde}	8.3^{a}	39.9^{ab}	4.5^{a}	83.7^{ab}	8.4^{bc}	45.5^{a}
Weedy-23DAS	5.1^{ab}	78.3^{ab}	8.5^{a}	43.2^{ab}	4.7^{a}	84.2^{ab}	8.8^{ab}	45.6^{a}
Weedy-28DAS	4.5^{bcd}	76.7^{abc}	8.6^{a}	40.1^{ab}	4.6^{a}	85.9^{a}	8.8^{ab}	47.2^{a}
Weedy-33DAS	4.4^{bcd}	74.9^{bcd}	7.7^{b}	40.2^{ab}	3.5^{bc}	80.5^{bc}	9.1^{a}	41.2^{ab}
Weedy-38DAS	4.2^{cd}	73.4^{cde}	7.6^{bc}	36.5^{ab}	3.3^{cd}	79.3^{cde}	7.9^{cd}	36.6^{bc}
Weedy-43DAS	3.6^{d}	72.8^{de}	7.6^{bc}	36.1^{ab}	3.2^{d}	77.7^{def}	7.7^{de}	36.4^{cb}
Weedy-48DAS	2.6^{e}	71.1^{e}	7.2^{cd}	33.4^{b}	2.8^{e}	75.9^{ef}	7.1^{e}	35.2^{bc}
Weed free	5.4^{a}	78.8^{a}	8.7^{a}	45.2^{a}	4.6^{a}	86.4^{a}	9.2^{a}	47.5^{a}
Weedy (check)	2.5^{e}	70.6^{e}	6.8^{d}	33.2^{b}	2.4^{f}	75.4^{f}	6.8^{f}	33.3^{c}
CV	12.5	2.8	3.3	15.5	4.6	2.7	4.9	15.5
LSD	***	***	***	***	***	***	***	**

LSD= List significant difference at different at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly different. PT= plant tillers, PH=plant height.
Source: Field experiment year of 2019/2020

while significantly minimum grain yield was obtained from a weedy check.

The grain yield from Pallas 45 OD treatment plot was higher than untreated plot in both locations, which could be attributed to the herbicide's effectiveness in managing all weed species at once or being most effective during the crop's weed competition phase of 18 to 28 DAS. According to Terefe et al. (2016), the critical periods of weed competition in the wheat range between 15 to 45 days after sowing (DAS). Previous study also reported that 60 days of sowing there is no economic benefit to eradicate weeds from wheat crop (Ahmad and Shaikh, 2003).

Biomass yield

The significant higher biomass yield was weighted in the early competition period was recorded from weed-free plot (9.8 and 10.4 t/ha) followed by herbicide treated plot (Table 3). The lowest was recorded from the weedy check (5.7 and 7.6 t/ha). The biomass yield increased significantly with a decrease in the competition period (Table 3).

Harvest index (HI %)

Harvest index was significantly affected by herbicide

Table 3. Effect of Pallas 45 OD application on yield and yield attributing traits in Amibara and Fentale districts, 2019/2020.

Competition	Amibara			Fentale		
period	TSW	BY	GY	TSW	BY	GY
weedy-13DAS	28.7^{cd}	7.9^{b}	2.6^{bc}	32^{de}	9.1^{abc}	3.2^{d}
Weedy-18DAS	31.7^{ab}	8.3^{b}	3.3^{a}	33.7^{abcd}	10.0^{ab}	4.0^{ab}
Weedy-23DAS	32.0^{ab}	8.4^{b}	3.4^{a}	34^{abc}	10.1^{a}	4.1^{ab}
Weedy-28DAS	33.0^{a}	8.3^{b}	3.5^{a}	34.7^{ab}	10.1^{a}	4.0^{ab}
Weedy-33DAS	30.7^{abc}	7.8^{b}	2.7^{b}	33^{bcd}	9.9^{ab}	3.6^{cb}
Weedy-38DAS	29.3^{bcd}	6.7^{c}	2.2^{c}	32.7^{cde}	9.1^{abc}	3.0^{cd}
Weedy-43DAS	28.0^{cd}	6.2^{cd}	2.1^{c}	32.3^{cde}	8.6^{bcd}	2.6^{d}
Weedy-48DAS	27.7^{d}	6.0^{cd}	1.9^{d}	31^{e}f	8.3^{cd}	2.4^{d}
Weed free	33.3^{a}	9.8^{a}	3.5^{a}	35.3^{a}	10.4^{a}	4.3^{a}
Weedy (check)	27.0^{c}	5.7^{d}	1.3^{e}	29.3f	7.6^{d}	1.6^{e}
CV	5.7	6.3	4.6	3.3	9.7	11.4
LSD	**	***	***	** *	**	***

*TSW=Thousand seed weight, BY= Biomass yield, GY= Grain yield.
Source: Field experiment year of 2019/2020

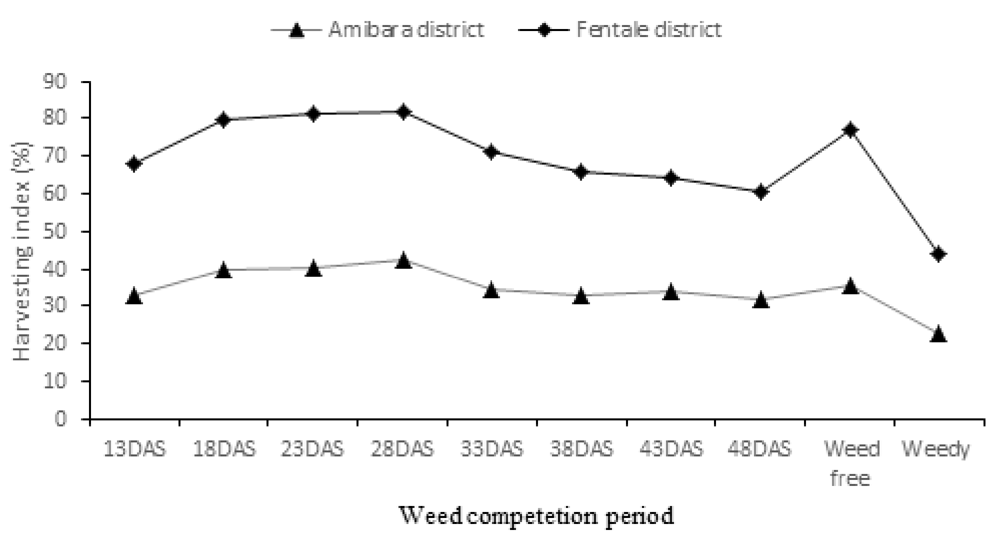

Figure 1. Harvesting index with different weed competition periods in Amibara and Fentale districts.
Source: Field experiment year of 2019/2020

application (Figure 1). The highest harvest index was recorded from weed-free (35.7 and 41.3%). whereas, the lowest harvest index was recorded in weed check control treatment (22.8 and 21.1%) (Figure 1). The variance in harvest index seen during distinct weed competition periods could be attributed to differences in the number of effective tillers, the number of grains per spike, 1000 seed weight, biomass yield, and grain yield. In agreement with this finding, Nano and Firdissa (2012) found that well-managed weeds had a higher harvest index (50%) than other treatments on the same variety. The large rise in harvest index with optimum period weed management might be due to weed suppression, which increased the availability of plant nutrients, soil moisture, and space to the wheat crop, favoring the usage of photosynthates for greater grain yield production.

Relative yield loss (%)

Yield loss of wheat was affected significantly by weed competition periods (Figure 2). Maximum grain yield loss was recorded in weedy check and minimum yield loss was recorded from weed crop computational periods of 18, 23 and 28 days in both locations (Figure 2). Grain yield loss rose dramatically throughout studied locations

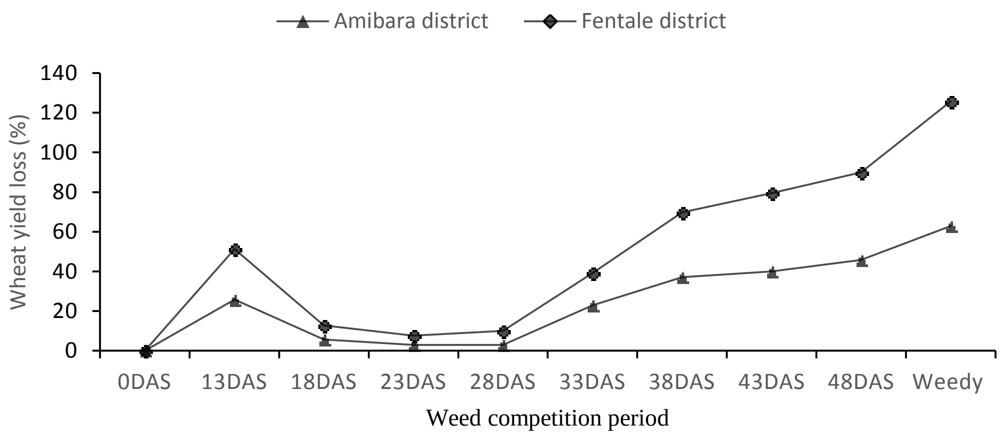

Figure 2. Yield losses with different weed competition in Amibara and Fentale districts.
Source: Field experiment year of 2019/2020

as the competition period increased. According to Rajput et al. (1987) allowing weeds growing in wheat up to 30 days has not significant effect on yield loss. Yield loss caused by weed infestations in wheat ranges from 10-65% (Bogale, 2020).

Phytotoxicity effect on plant growth

The visual field observation revealed that the most phytotoxicity symptoms were detected on herbicide sprayed plots on 8 days after irrigated as opposed to 3 days after irrigated. When Pallas 45 OD was applied to non-moist soil, the wheat plant yellowed and took a long time to return to its original color or green. To reduce plant phytotoxicity and maximize herbicide efficiency, the wheat crop should be irrigated 2 to 3 days before herbicide application. This also makes it easier for the sprayer man to walk on the irrigated area and keeps the worker from being interrupted by the muck. In general, when there is a drought, the irrigation schedule and herbicide treatment timing should be planned concurrently. In this case, irrigation water is applied at 10-day intervals.

CONCLUSION AND RECOMMENDATION

The current study confirmed that proper time of herbicide (Pallas 45 OD) treatment is very effective at the early weed growth stage; but, when applied after the critical period of 28 days, it is ineffective in controlling old stage weeds. Weeds must be controlled within 18 to 28 days after wheat crop planting to reduce the possibility of economic yield loss, as this is the critical period of weed crop competition in wheat crops. Furthermore, proper weed management at the right time might produce a larger number of productive tillers, plant height, grain per spike, crop biomass production, and grain yield. Therefore, if weeds are not suppressed during the crop-weed critical period, incorrect weed management can result in yield losses of up to 62.8%.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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