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Author(s): Baidhawi

The Effectiveness of Mixing Herbicides and Manual Weed Control on Corn (*Zea mays* L)

Baidhawi[1*)]
[1]Agroecotechnology Study Program, Faculty of Agriculture,
Universitas Malikussaleh, Lhokseumawe
Reuleut Campus, Aceh, Aceh Utara.
*Corresponding Author : baidhawi@unimal.ac.id

Abstract

Field trials were conducted in Janauy 2021 cropping seasons to evaluate some herbicide mixtures and manual weed control method in the maize production. The experiment consisted of 10 treatments as follows: Metolachlor + atrazine (1.0 + 2.0 kg a.i./ha), metolachlor + atrazine (2.0 + 2.5 kg a.i./ha), metolachlor + atrazine (3.0 + 3.0 kg a.i./ha), pendimethlin + atrazine (1.0 + 2.0 kg a.i./ha), pendimethlin + atrazine (2.0 + 2.5 kg a.i./ha), pendimethlin + atrazine (3.0 + 3.0 kg a.i./ha), metolachlor + atrazine (1.0 + 2.0 kg a.i./ha) plus one supplementary hoe weeding (SHW) at 6 weeks after sowing (WAS) and pendimethlin + atrazine (1.0 + 2.0 kg a.i./ha) plus one SHW at 6 WAS, hand weeding at 3 and 6 WAS and a weedy check. These treatments used in randomized complete block design with three replicates. The rsults showed that metolachlor + atrazine and pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha plus one SHW at 6 WAS significantly reduced weed infestation and gave higher maize grain yield and economic returns. These methods are therefore recommended to farmers as alternative to two hand weeding at 3 and 6 WAS.

Keywords: *Chemical Weed Control, Hand Weeding, Weed Infestation, Corn, and Productivity.*

INTRODUCTION

Corn is one of the most important food crops in the world after rice and wheat. Corn serves as livestock, and industrial food, where more than 55% of domestic corn needs are used as feed, 30% as food consumption, and the rest are for industrial needs. (Yusuf et al., 2013). Domestic and foreign market demand for corn commodities tends to increase every year for both food and non-food needs. Corn production at the national level in 2019 reached 29.93 million tons of dry shells or decreased by 0.55 million tons compared to 2018 (BPS, 2020).

Although the main staple crop, corn yields obtained in Indonesia are far below expectations due to many influencing factors, one of which is the presence of weeds, soil fertility, and labor. Yield losses due to the presence of weeds ranged from 60–80% caused by uncontrolled weeds in maize (Lagoke et al., 1998). Other studies also agree with Imoloame and Omolaiye (2016), who reported 89% loss of maize yields due to the weeds.

Manual weeding is the most common weed control method in Indonesia. Manual weed control is considered to be ineffective, requires a lot of labor, takes a relatively long time, and is relatively high cost, especially in large areas, and the latter method is still the method that farmers in Indonesia rely on (Rao et al., 2008; Most, 2002; Shantakumar 2003). Furthermore, Adigun & Lagoke (2003) explained that the yield loss reached 40–60%. Furthermore, Ekeleme (2009) stated that 25–55% of the total production cost was spent on labor and weeding.

Weed control with herbicides is considered practical and economical compared to weeding. Herbicides are applied to prevent weeds from planting to harvesting so that yields can increase. The use of herbicides can increase the efficiency of weed control to increase corn yields and reduce labor costs (Imoloame, 2014).

Several important weaknesses that arise from the use of herbicides are: (1) only able to control weeds from certain groups, while weeds in soybean plantations consist of various groups; (2) the continuous use of a type of herbicide will form resistant weeds so that it will be so difficult to control them; (3) the emergence of weed resistance will increase weed management problems, such as the increase of control costs, the emergence of prolonged competition due to not controlling weeds, and so on. (Rao, 2008). One possibility to anticipate the weaknesses above is to combine or mix one herbicide with other herbicides and combine two or more weed control methods (Vencill et al., 2018).

Integrated weed control is a combination of two or more weed control methods for more effective and efficient weed control than a single method. This approach considers local wisdom, cultivation, and socio-economic conditions (Ganie et al., 2014; Norsworthy et al., 2012). This study aims to determine effective and efficient weed control methods and provide higher maize yields.

MATERIALS AND METHODS

The experiment was carried out from July to December 2020 in Lungdaneun Village, Peusangan Siblah Krueng subdistrict, Bireun Regency, Aceh Province, with a height of 31 m above sea level. The soil at the experimental site was the order Inceptisol, while the climate type based on rainfall over the last ten years includes C (slightly wet), according to Schmidt and Ferguson (1951). The experiment used a Randomized Block Design (RAK) consisting of 10 (ten) treatments, namely: A (metolachlor + atrazine at a dose of 1.0 + 2.0 kg ba/ha), B (metolachlor + atrazine at a dose of 2.0 + 2.5 kg ba/ha), C (metolachlor + atrazine at a dose of 3.0 + 3.0 kg w/ha), D (pendimethalin + atrazine at a dose of 1.0+2.0 kg w/ha), E (pendimethalin + atrazine at a dose of 2.0 + 2.5 kg w/ha), F (pendimethalin + atrazine at a dose of 3.0 + 3.0 kg ba/ha), G (metolachlor + atrazine at a dose of 1.0 + 2.0 kg ba/ha + manual weed control at 6 WAP), H (pendimethalin + atrazine at 1.0 + 2.0 kg ai/ha + manual weed control at 6 WAP), I (weeding at 3 and 6 WAP) J (No Weed Control).

The soil for the experiment site was analyzed for its physical and chemical properties to determine its general characteristics. Before tillage, weed inventory was carried out at the experimental site. The vegetation analysis method used is the quadratic method (Tjitrosoedirdjo et al., 1986). The soil was plowed and harrowed to crumbs, and then plots were made 600 x 200 cm. Corn planting was carried out individually with a depth of 3 cm, and each planting hole was filled with two corn seeds with a spacing of 75 x 25 cm. After the corn plants are 10 days old, thinning was done by leaving 1 (one) plant per planting hole. Corn plants were fertilized with a dose of 200 kg ha-1 Urea, 150 kg ha-1 SP 36, and 50 kg ha-1 KCl given at the time of planting. Fertilization was given with a row of plants as far as 5 cm at a depth of 3 cm above the soil surface. Herbicide application as a treatment aimed to control weeds and was carried out according to the treatment and applied at planting. Herbicide mixing was based on the "tank-mix" method, which was mixed in a spray tank. The spray calibration technique was carried out so that the accuracy of spraying was maintained. The applicator used was a hand pressure sprayer with a flat fan of 8002 nozzles and a pressure of 250 kPa, and the volume of spray used was 500 L ha-1.

The responses observed in this experiment were:

- **Weed density** was observed at 6 and 12 Weeks After Planting (MST) by counting weeds based on species using Square Plots (1x1 m) in each experimental plot.
- **Weed dry weight** was observed at the 6 and 12 weeks after planting (WAP) in each treatment plot of 2 0.25 m2 sample plots. Weeds were first removed and separated by weed type to calculate the weed dry weight value. After that, the weeds were dried to a constant rate using an oven for 48 hours at 90oC.
- Relative Importance Value was observed before planting, where 21 and 42 DAP using a sample plot of 0.5 m2. This observation examined the types of weeds that were dominant in each observation and treatment. Relative Importance Value can be determined by calculating Absolute Density, Relative Density, Absolute Dominance, Relative Dominance, and Relative Frequency.

$$\text{Relative Importance Value} = \frac{FR + DR + FR}{3}$$

- ***Corn Plant Height***

Observation of plant height from the base of the stem or soil surface to the tip of the longest leaf.

- The yield of dry seeds per plot (g) was the result of weighing all dry seed yields harvested on a tiled plot of 160 x 100 cm.

RESULTS AND DISCUSSION

Density and Dry Weight

The application of pendimethalin + atrazine at 1.0 + 2.0 kg ba ha-1/coupled with weeding at 6 WAP (treatment G) and metolachlor + atrazine at 1.0 + 2.0 kg ba ha-1 coupled with weeding at 6 WAP (treatment H) can cause a significant reduction in weed dry weight compared to other weed control methods. However, this effect was not significantly different from the weeding methods at 3 and 6 WAP (treatment I). No weed control (control) gave a significantly higher dry weight of weeds compared to other treatments (Table 2). At 12 WAP observations, treatments G, H, and I could give weed dry weight significantly lower than other treatments (Table 1).

The application of pendimethalin + atrazine at 1.0 + 2.0 kg ba ha-1/coupled with weeding at 6 WAP (treatment G), metolachlor + atrazine at 1.0 + 2.0 kg ba ha-1 accompanied by weeding at 6 WAP (treatment H), and weeding at 3 and 6 WAP (treatment I) was more effective in reducing weed density and weed cover significantly compared to other treatments (Table 2).

The ability of pendimethalin + atrazine at 1.0 + 2.0 kg ba ha-1 was accompanied by weeding at 6 WAP (treatment G), metolachlor + atrazine at 1.0 + 2.0 kg ba ha-1 coupled with weeding at 6 WAP (treatment H), and weeding Weeds at 3 and 6 WAP (treatment I) were more effective in suppressing weed dry weight, weed density, and weed cover. It proved that these treatments were effective in suppressing weed growth, and mixing these different herbicides plus one weeding at 6 WAP can be used to control weeds in the corn crops. The integration of herbicides with a single weed has proven to be very effective in controlling weeds and increasing higher yields in a variety of crops. This study was in line with the studies conducted by Imoloame (2014), Peer et al. (2013), and Veeramani et al. (2001).

Table 1. The Effect of Mixing Herbicides and Manual Weed Control on Weed Dry Weight (g).

Treatments	dose (kg b.a/ha^{-1})	Observation Priods	
		6 WAP	12 WAP
P+A	1.0 + 2.0	229.8 a	537.5 ab
P+A	2.0 + 2.5	234.2 a	420.3 ab
P+A	3.0 + 3.0	112.5 a	426.4 ab
M+A	1.0 + 2.0	544.9 a	284.6 b
M+A	2.0 + 2.5	504.3 a	469.2 ab
M+A	3.0 + 3.0	124.4 a	103.6 b
P+A+Weeding 4 WAP	1.0 + 2.0	289.8 a	134.8 b
M+A+ Weeding 8 WAP	1.0 + 2.0	155.9 a	163.9 b
Weeding 3 and 6 WAP	-	43.3 a	261.5 b
Control (Weed)	-	252.9 a	857.8 a

Note: The numbers marked with the same lowercase letter in the same row and the same capital letter in the same column were not significantly different according to the DMRT 0.05 test.

Table 2. The Effect of Mixing Herbicides and Manual Weed Control on Density (m2) and Weed Cover Percentage (%).

Treatments	dose (kg b.a/ha^{-1})	Observation Priods	
		6 WAP	12 WAP
P+A	1.0 + 2.0	5.0 b	31.6 b
P+A	2.0 + 2.5	3.3 bc	32.0 b
P+A	3.0 + 3.0	2.7 bc	33.2 b
M+A	1.0 + 2.0	4.6 bc	21.6 b
M+A	2.0 + 2.5	4.4 bc	31.5 b
M+A	3.0 + 3.0	3.8 bc	31.4 b
P+A+Weeding 4 WAP	1.0 + 2.0	2.3 bc	11.2 b
M+A+ Weeding 8 WAP	1.0 + 2.0	2.1 c	15.8 b
Weeding 3 and 6 WAP	-	1.7 c	17.6 b
Control (Weed)	-	10.0 a	142.2 a

Note: The numbers marked with the same lowercase letter in the same row and the same capital letter in the same column were not significantly different according to the DMRT 0.05 test.

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Table 3. RIV Values (*Relative importance value index*) of Weed species at 6 WAP observations (Week After Planting).

Weed Species	Treatments										RIV
	A	B	C	D	E	F	G	H	I	J	
Grass											
Paspalum conjugatum	51.0	48.7	46.6	42.0	53.8	37.7	70.2	56.0	45.7	42.3	49.4
Digitaria horizontalis			6.2	6.0		12.6		12.5		3.6	4.1
Setaria barbata	7.5			15	11.4	11.2		31.5		7.0	8.4
Rottboellia cochinchinensis	10.9			12	26.9	38.6					8.8
Chloris pilosa									10		1
Riddle											
Mariscus alternifolius	10.7	29.2	11.8	13.2			7.5		8.5	10.4	9.1
Cyperus rotundus			9								0.9
Pycreus lanceolatum		5.4	4.5						14	11.4	3.5
Kilinga squamatulata		5.4					7.5		8.5	2.9	2.4
Cyperus esculentus	6.1										0.6
Broadleaf											
Gonphrena celosoides	8.8		5.5	6.0	8				7.0	9.4	4.5
Hyptis suaveolens		6.1	4.8						6.5	3.2	2.1
Agyratum conizoides			6.2								0.6
Euphorbia heterophylla			5.2								
Vernonia galamensis							14.9			6	2.1
Ludwigia *deccurens*	6.1									34.1	4.0
Commelina benghalensis		5.4									0.5
Portulaca oleracea				6							0.6
Total	7	6	9	7	4	4	4	3	7	10	

Relative Importance Value

The relative importance value of each weed species that infested corn in each treatment was presented in Tables 3 and 4. Paspalum conjugatum was the most dominant weed species both in and in all treatments at 6 WAP and then was followed by Rottboellia cochinchinensis and Mariscus alternifolius. Weeds Paspalum conjugatum, Rottboellia cochinchinensis, and Mariscus alternifolius were very dominant in the pendimethalin + atrazine treatment at 1.0 + 2.0 kg b.a ha-1. There were 7 weed species that appeared in the treatment (6 WAT observations). At 12 WAP, there was an increase to 11 species, including Paspalum conjugatum, Setaria barbata, Hyptis suaveolens, and Commelina benghalensis as the most dominant (Table 4).

The higher dose of pendimethalin + atrazine application made Paspalum conjugatum and Maniscus alternifolius weeds the most dominant weed species and were important weeds growing in maize at 6 WAP. However, at 12 WAP, there was a succession of weeds, where there were other weed species that appeared and were the most dominant, namely; Kyllinga erecta, Paspalum conjugatum, Hyptis suaveolens, and Cyperus esculentus. In the treatment that applied pendimethalin + atrazine at a dose of 2.0 + 2.5 kg ba ha-1 and pendimethalin + atrazine at 3.0 + 3.0 kg ha-1, Kyllinga erecta Pasphalum conjugatum and Commehlina benghalesis were dominant in that treatment. The total number of weed species under this treatment increased from 6 and 9 at 6 WAP (Table 3) to 8 and 10 at 12 WAP, respectively (Table 4).

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Table 4. RIV Values (*Relative importance value index*) of Weed species at 12 WAP observations (Week After Planting).

Weed Species	Treatments										RIV
	A	B	C	D	E	F	G	H	I	J	
Grass											
Paspalum conjugatum	29.6	23.2	21.8	24.8	21.6	21.5	27.6	25.7	24.4	12.1	23.2
Digitaria horizontalis				14.2	30.0				4.7	16.6	6.6
Setaria barbata	18.5		4.1	22.9	24.4	31.7	5.2	6.5	18.3	24.4	15.6
Rottboellia cochinchinensis	4.4	3.9		2.9	6.7		6.8	3.4	3.1	2.1	3.3
Chloris pilosa	2.5							5.1	2.7	1.7	1.2
Setaria pumila	4.9										0.5
Mariscus alternifolius		3.9								2.3	0.62
Dactyloctenium aegyptium				2.9						4.1	0.7
Brachiaria alata										1.7	0.2
Kilinga squamatulata											
Cyperus iria	2.5								2.7	1.7	1.2
Cyperus rotundus										2.1	0.21
Pycreus lanceolatum				2.9							0.3
Kyllinga squmatulata								3.7			0.4
Cyperus esculentus	6.7	11	7.8	5.8			12.6	5.7	7.4	7.4	6.4
Cyperus difformis									2.7	1.7	0.3
Kyllinga erecta		17	19.3				17		6.4		6
Ludwigia *deccurens*											
Gomphrena celosoides	3.2		14.7	5.3	3.5	24.5	6.8	17.6	7.0	5.8	8.8
Hyptis suaveolas	11.6	16.6	4.5	5.4	7.2	11.8	6.8	18.3	8.9	4.2	8.4
Euphorbia heterophilla			3.7			5.0					0.9
Vernonia galamensis	5.5	7.4	5.3	10.2		5.7	13.1	9.8	5.8	5.4	6.8
Leucas martinicensis			6.7	2.9	3.2					2.6	1.5
Commelina benghalensis	10.6	7.1	12.4		3.5						4.0
Hyptis lanceolata							3.6	5.1			1.3
Portulaca Oleracea										2.2	0.2
Total	**11**	**8**	**10**	**11**	**8**	**6**	**9**	**10**	**13**	**17**	

The most dominant weeds in metolachlor + atrazine treatment at all levels were Paspalum conjugatum, Setaria barbata, and Rottboellia cochinchinensis at 6 WAP, while at 12 WAP, Paspalum conjugatum and Setaria barbata maintained their dominance in all of these treatments. Other weed species that were dominant in the metolachlor + atrazine treatment at 1.0 + 2.0 and 2.0 + 2.5 kg a.i./ ha were Digitaria horizontalis and Gomphrena celosoides, while the species Hyptis suaveolens became dominant in the metolachlor + atrazine treatment at 3.0 + 3.0 (Table 3). Table 4 also showed an increase in the number of weed species that infest maize at 12 WAP.

The dominant weed species at 6 WAP applied with pendimethalin + atrazine at 1.0 + 2.0 kg a.i./ha accompanied by weeding at 6 WAP (treatment G) were Paspalum, conjugatum, and Vernonia galamensis. However, at 12 MST, Paspalum conjugatum, Vernonia galamensis, and Cyperus rotundus were more prominent. Paspalum conjugatu, Setaria barbata, and Digitaria horizontalis were the most common weed species in metolachlor + atrazine treatment at 1.0 + 2.0 kg ha-1 coupled with weed control at 6 WAP, but at 12 WAP, the dominant weed was Paspalum conjugatum, Gomphrena celosiodes, and Hyptis suaveolens (Tables 3 and 4).

Weeding at 6 WAP (treatment I) showed that Paspalum Conjugatum, Pycreus Lanceolatus, and Chloris Pilosa were the dominant weed species at 6 WAP (treatment I), but at 12 WAP, the dominant weeds were Paspalum Conjugatum and Setaria Barbata. Observations at 6 WAP for the control treatment (J), the dominant weeds were Paspalum Conjugatum, Ludwigia decurrens, Pycreus Lanceolatus, and Mariscus Alternifolius (Table 3), but at 12 WAP, Setaria barbata, Digitaria horizontalis, and Paspalum Conjugatum were the most dominant weeds (Table 4).

Table 3 showed that at 6 WAP, Paspalum conjugatum was the most dominant weed in all treatments, followed by Mariscus altenifoluis, Rottboelia cochinchinensis, and Setaria barbata in descending order (Table 3). However, at 12 WAP, the same thing happened for Paspalum conjugatum as the most dominant weed, followed by Setaria barbata, Gomphrena celosoides, and Hyptis suaveolens. (Table 4). It explained that Paspalum conjugatum was the most dominant weed species present in maize for all treatments at 6 and 12 WAP due to the inability of the treatment to control this weed species because it could adapt well to the environment.

The adaptability of this weed species made it more competitive with corn crops. It is in line with the findings of Imoloame and Omolaiye (2016) that the types of weeds with the highest relative importance in maize are Paspalum canjugatum and Digitaria horizontalis. The grass weeds were reported to be more competitive and able to suppress the growth of corn plants. The significant decrease in corn yield due to the presence of weeds could be due to the dominance of Paspalum conjugatum weeds. Table 4 also showed an increase in the number of weed species by 12 WAP for each treatment. It could be due to the proliferation of more weed species over time because the effects of herbicides have disappeared.

Table 4 also showed that the emergence of broadleaf weeds as the dominant weed species at 12 WAP indicated that broadleaf weeds appeared at the end of the season. Rao (2008) explained that 60–75% of grass-fed weeds appear at the beginning of corn planting, while broadleaf only 30-35%.

Corn Plant Height

Table 5 showed that all treatments with herbicides gave significantly higher plant height compared to the weed treatment (control) at 6 WAP, but overtime at 12 WAP, weeding at 3 and 6 WAP gave significantly higher plant height compared to other treatments, except treatment G (metolachlor + atrazine and pendimethalin at 1.0 + 2.0 kg ba ha-1) and treatment H (metolachlor + atrazine at 3.0 + 3.0 kg ba ha-1).

Weeding treatment at 3 and 6 WAP (treatment I) and mixing treatment of two different herbicides integrated with weeding at 6 WAP would give significantly higher crop yields than other treatments because the treatment could significantly reduce weed infestations compared to other treatments. This treatment minimized competition with weeds and made sufficient growth resources (moisture, plant nutrients, light) for the better utilization of corn corp. In addition, it could provide an advantage for maize because it could capture more solar radiation to increase photosynthesis and higher yields.

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Table 5. The Effect of Mixing Herbicides and Manual Weed Control on Corn Plant Height (cm).

Treatments	Dose (kg b.a/ha^{-1})	Observation Priods	
		4 WAP	8 WAP
P+A	1.0 + 2.0	64.9 ab	172.7 bc2
P+A	2.0 + 2.5	69.9 a	165.8 bc
P+A	3.0 + 3.0	60.2 ab	163.6 bc
M+A	1.0 + 2.0	57.0 bc	170.4 bc
M+A	2.0 + 2.5	63.0 ab	173.7 bc
M+A	3.0 + 3.0	60.9 ab	174.8 ab
P+A+Weeding 4 WAP	1.0 + 2.0	67.4 ab	179.2 ab
M+A+ Weeding 8 WAP	1.0 + 2.0	65.3 ab	190.1 ab
Weeding 3 dan 6 WAP	-	67.7 ab	203.7 a
Control (Weed)	-	52.5 c	156.9 c

Note: The numbers marked with the same lowercase letter in the same row and the same capital letter in the same column were not significantly different according to the DMRT 0.05 test.

Corn Crop Yield

Weeding at 3 and 6 WS (treatment I) yielded the same results as treatments G (application of pendimethalin + atrazine at 1.0 + 2.0 kg ai/ha coupled with weeding at 6 WAP) and H (metolachlor + atrazine at 1.0 + 2.0 kg ba ha-1 coupled with weeding at 6 WAP) but was significantly higher than treatment J (Table 6).

The higher yield of corn kernels produced by treatments G and H and weeding at 3 and 6 WAP compared to other weed control methods was the result of better weed control by this treatment, which can increase growth, development, and higher yields. The control treatment gave significantly lower yields due to significantly higher dry weight of weeds, weed density, and weed cover, which caused high competition with weeds for water, light, and plant nutrients resulting in lower yields. These results are similar to those of Imoloame (2014) and Veeramani et al. (2001), who reported increased yields caused by the use of herbicide applications together with weeding.

Table 6. The Effect of Mixing Herbicides and Manual Weed Control on Corn Crop Yield (g)

Treatments	Dose	Dried Seeds/Plot
P+A	1.0 + 2.0	1,817.1 bc
P+A	2.0 + 2.5	1,594.3 bc
P+A	3.0 + 3.0	1,301.5 cd
M+A	1.0 + 2.0	1,126.7 de
M+A	2.0 + 2.5	1,172.4 de
M+A	3.0 + 3.0	1,304.7 cd
P+A+Weeding 4 WAP	1.0 + 2.0	2,045.7 ab
M+A+ Weeding 8 WAP	1.0 + 2.0	2,385.7 ab
Weeding 3 and 6 WAP	-	2,782.7 a
Control (Weed)	-	633.6 e

Note: The numbers marked with the same lowercase letter in the same row and the same capital letter in the same column were not significantly different according to the DMRT 0.05 test.

CONCLUSIONS

The application of mixed herbicides metolachlor + atrazine and pendimethalin + atrazine with a mixed dose of 1.0 + 2.0 kg b.a ha-1 plus weeding at 6 WAP and weeding at 3 and 6 WAP was effective in controlling weeds and giving higher yields. Weeding at 3 and 6 WAP is the most widely used method by farmers but requires high costs, takes a long time, and requires a lot of labor. The application of a mixture of herbicides metolachlor + atrazine and pendimethalin + atrazine with a mixed dose of 1.0 + 2.0 kg b.a ha-1 plus weeding at 6 WAP can be an alternative weed control in corn.

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