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EFFICACY OF PARAQUAT AND GLYPHOSATE APPLIED IN WATER SOLVENTS FROM DIFFERENT SOURCES TO CONTROL WEEDS IN OIL PALM PLANTATION

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ABSTRACT

The research was conducted to identify weeds in oil palm plantation and to evaluate the efficacy of paraquat and glyphosate applied in water carrier from different sources including distilled, well, and river water. Nine dominant weeds based on summed dominance ratio (SDR) are Ottocloa nodosa, Cyclosorus aridus, Dryopteris affinis, Panicum repens, Axonopus compressus, Paspalum conjugatum, Borreria latifiola, and Stachytarpheta jamaicensis, and Dryopteris filix-mas. Paraquat showed a very strong efficacy at 2 weeks after applied which reached 92.0, 88.0, and 86.0 percent of efficacy, while glyphosate showed a very strong efficacy at 8 weeks after applied which reached 92.7, 89.7, and 87.3 percent of efficacy applied in distilled, well, and river water solutions, respectively. The efficacy of paraquat and glyphosate persisted up to 8 and 16 weeks, respectively. Some weeds which were tolerant to paraquat were Paspalum conjugatum (grass), Ottochloa nodosa (grass), Panicum repens (grass), Cyclosorus aridus (fern), and Borreria latifolia (broadleaf). Three different sources of water carrier including distilled, well, and river water did not influence neither paraquat nor glyphosate efficacy.

Keywords: glyphosate, oil palm plantation, paraquat, water quality, weed control.

1. INTRODUCTION

One major problem in oil palm cultivation is weeds because of a decreased crop yield due to weeds reaching more than 20% (Tjitrosoedirdjo *et al*., 1984; Fitri, 2013). Weeds compete with crops for growing space, sunlight, and nutrients (Monaco *et al*., 2002). Some of the major weeds in oil palm plantation in Indonesia are Axonopus compressus, Cyrtococcum patens, Imperata cylindrica, Mikania micrantha, Ottochloa nodosa, Passpalum conjugatum, Cyclosorus aridus, and Panicum repens (Fitri, 2013). Management of weeds is necessary in order to prevent harmful effects on the growth and production of oil palm (Tjitrosoedirdjo *et al*., 1984; Salmiyati *et al*., 2014). Some considerations in integrated weed management are to destroy noxious weeds, control soft weeds, apply integrated control and preserve vegetation that may be useful as a host of predators (Tjitrosoedirdjo *et al*., 1984; Fitri, 2013 Salmiyati *et al*., 2014). Using herbicide in weed management in plantations is an appropriate choice because it is more effective and efficient (Tjitrosoedirdjo *et al*., 1984; Mohamad *et al*., 2010; Salmiyati *et al*., 2014).

Paraquat and glyphosate are widely used herbicides in plantations (Traore *et al*., 2010; Wibawa *et al*., 2010; Thongjua and Thongjua, 2015). Paraquat (1, 1'-dimethyl-4, 4'-bipyridinium dichloride) is a contact herbicide and non-selective to broadleaf and grass weeds (Ahrens, 1994). Paraquat solutions are applied foliar and destroy plant tissue rapidly. Paraquat ion can also bind to electrons and form oxidized free radicals which produces hydrogen peroxide (H_2O_2) that are very toxic to the plants by inhibiting the formation of NADPH in photosynthetic reaction. The symptoms are characterized by dry leaves and weeds die in less than two weeks (Ahrens, 1994; Monaco *et al*., 2002).

Glyphosate (N-[phosphonomethyl] glycine), formulated as an isopropylamine salt, is a broad spectrum and systemic herbicide used to control weeds directly (Ahrens, 1994). It is applied foliar to the leaves, absorbed and translocated through phloem into the maristematic tissues of plants (Ahrens, 1994; Monaco *et al*., 2002). Glyphosate inhibits the EPSP (5-enolpyruvyl shikimate 3-phosphate) enzyme which plays a role in the biosynthesis of aromatic amino acids include tryptophan, tyrosine, and phenylalanine. The symptoms are wilted, brown leaves, and eventually die four weeks after herbicide applied (Monaco *et al*., 2002; Duke and Powles, 2008).

Paraquat and glyphosate are generally applied in water solution (Ahrens, 1994). The quality of water used for pesticide carrier can greatly affect the efficacy of herbicide (Chahal *et al*., 2012; Mahoney *et al*., 2014). Some properties of water that may reduce herbicide efficacy are high pH, water hardness, alkalinity, and turbidity (Thelen *et al*., 1995; Hoffman *et al*., 2008; Chahal *et al*., 2012; Aliverdi *et al*., 2014). The ideal pH of water ranges from 3 to 5. High pH is caused by hard water which contain high levels of Ca^{2+}, Mg^{2+}, Na^{+}, or $Fe^{2+/3+}$ cations. Herbicide molecules dissociate if pH is over 7 and form negatively charged molecules that may attach to cations of hard water making the herbicide ineffective (Thelen *et al*., 1995; Chahal *et al*., 2012).

Alkalinity refers to carbonate and bicarbonate levels in water. If bicarbonate is more than 500 ppm, it would reduce herbicide efficacy (Chahal *et al*., 2012). Turbidity is caused by suspended solids, soils, and organic matters which can reduce herbicide effectiveness. Clear and odorless water indicate no turbidity are very important for the effectiveness of herbicide efficacy (Hoffman *et al*., 2008; Chahal *et al*., 2012; Mahoney *et al*., 2014). This experiment was aimed to identify weeds in oil palm

ARPN Journal of Agricultural and Biological Science

plantation in Bengkulu, Indonesia and to evaluate the effect of water from different sources as a spray carrier on efficacy of paraquat and glyphosate.

2. MATERIALS AND METHODS

The research was conducted on weed vegetation in the productive oil palm plantation from January to May 2015. The field was located in District of Muara Bangkahulu, Bengkulu, Indonesia at geographical position 03^{o} 46' 43.3" South, 102^{o} 17.46' 8" East, and altitude at 15 meters above the sea level. The treatments evaluated were comprised of paraquat solutions using distilled, well, and river water carrier; glyphosate solutions using distilled, well, and river water carrier; and untreated as a control. Each treatment plot of 3m x 4m size was arranged randomly among the oil palm trees. The experiments were organized in completely randomized block design (CRBD) with three replications. Paraquat and glyphosate solutions were directly sprayed to weeds in the treatment plots and the spray solutions were prevented from the oil palm trees. The 400 L per hectare sprayed volume was delivered by knapsack sprayer with flat fan nozzel at a pressure of 15 psi. Doses of paraquat and glyphosate were 600 and 1000 gram a.i. ha^{-1}, respectively.

Weed assessment in oil plantation was performed twice. Before the herbicide application, 10 wooden square-plots of 0.5 m x 0.5 m size were determined randomly among the tree of oil palms. At the end of experiments, weed analysis were done in two wooden square-plots for each treatment unit. Variables observed were density, frequency, and dominance of each weed species. Summed dominance ratios (SDR) were calculated in accordance to equation Tjitrosoeditdjo *et al*. (1984), equation (1).

$$\mathrm{SDR} = \frac{\mathrm{Dr+Fr+D'r}}{3} \quad (1)$$

Dr, Fr, and D’r are relative value of absolute density, frequency, and dominance of each weed species, respectively. The absolute values are the total of density, frequency, and dominance values of each weed species from the observed plots.

Mean of SDR before the herbicide application and SDR in control plots at the end of experiment were used to determine the rank of dominant weeds in the oil palm plantation, equation (2).

$$\text{Mean of SDR} = \frac{\mathrm{SDR{-}i} + \mathrm{SDR{-}f}}{2} \quad (2)$$

SDRi and SDRf were summed dominance ratio before the herbicide application and at the end of the experiment from control plots.

Variables observed after herbicide application were herbicide efficacy, regrowth, and biomass of weeds. Herbicide efficacy was observed visually every 2 weeks until 16 weeks by comparing weed controlled in treated to untreated plot. The intensities of herbicide efficacy were described in five levels including no herbicide efficacy, less efficacy, medium efficacy, strong efficacy, and very strong efficacy, with the scores being 0, 0 - 25, 25 - 50, 50-75, 75-100 %, respectively (Ngawit and Budianto, 2011).

The regrowth of weeds was observed visually at 16 weeks after herbicide applied by comparing percentages of the weed covered on treated to untreated plot. The scores ranged from 100 to 0 percent, where 100 means that all field surface were covered by weeds while zero means no weed grew on the soil surface (Burrill *et al*., 1976). The values of summed dominance ratio based on the weed coverage after the trials (SDR_1) were calculated by multiplication of SDR to the percentage of weed coverage.

Weed regrowth was also observed as dry weight of weed biomass at 16 weeks after herbicide application. Weeds were cut at the base of the stem from two squares plots in each experimental unit of 0.5 m x 0.5 m size and dried in an oven at 72 C for 3 x 24 hours. Data of weed biomass were presented in percent of control.

The water used as a herbicide carrier from three sources including distilled, well, and river water were analyzed in the laboratory for chemical and physical characteristics including pH, color, odor, and turbidity. Climatology data including monthly rainfall and number of rainy days were collected during the experiments.

Data of herbicide efficacy, weed regrowth or weed coverage, and dry weight of weed biomass were subjected to statistical analysis used a Software CoStat 6.4 (Cardinali and Nason, 2013). Means for significant influences of the treatments in ANOVA at the 5 % level were separated using Fisher’s LSD test at $P \leq 0.05$.

3. RESULT AND DISCUSSIONS

There were 18 species of weeds in oil palm plantation in Bengkulu which SDR values ranged from 9.96 to 3.11 and the average SDR was 5.56 (Table-1). Weeds were comprised of three groups which were broadleaf (B), grass (G), and fern (F) of 7, 7, and 4 species, respectively. Nine species of dominant weeds determined by the higher SDR than the average SDR were Ottochloa nodosa, Cyclosorus aridus, Dryopteris affinis, Panicum repens, Axonopus compressus, Paspalum conjugatum, Borreria latifiola, Stachytarpheta jamaicensis, and Dryopteris filix-mas, which the SDR were 9.96, 7.63, 7.16, 7.13, 6.76, 6.68, 6.30, 6.05, and 5.68 percent, respectively (Table-1).

Paraquat herbicide performed a very strong efficacy at 2 weeks after applied which were rated at 92.0, 96.0 and 88.0, respectively in distilled, well, and river water solutions (Table-2). Although paraquat caused the damage to the plant tissues rapidly, it was not permanent because paraquat efficacy decreased in the following observations. Herbicide efficacy is the ability of herbicide to kill weeds (Burrill *et al*., 1976).

General perception about herbicide efficacy in weed control was indicated by the rapid damage or injury tissues, but it is not desired if weeds do not die permanently (Burrill *et al*., 1976). Some species of perennial weeds may grow back vegetatively because herbicide could not kill vegetative parts of weeds such as roots, rhizome or stolon (Monaco *et al*., 2002). Some

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paraquat molecules were possibly translocated through the xylem and inhibited electron transport in photosynthetic reaction, thus destroying the plant tissues more permanently (Monaco *et al*., 2002).

In contrast to the paraquat, the efficacy of glyphosate appeared slow and very strong at 8 weeks after herbicide applied, which were 92.7, 89.7, and 87.3 percent efficacy in distilled, well and river water solutions,

Table-1. Weed assessment in the oil palm plantation determined by initial and final SDR.

No.	Weed species	Weed group	Initial-SDR	Final-SDR	Mean of SDR	Rank of dominant weeds
1	Ageratum conyzoides	B	3.80	3.38	3.59	16
2	Axonopus compressus	G	7.63	5.88	6.76	5
3	Borreria latifiola	B	5.80	6.79	6.30	7
4	Cyclosorus aridus	F	8.64	6.62	7.63	2
5	Cyperus kyllingia	G	4.93	3.42	4.18	14
6	Digitaria sanguinalis	G	3.90	2.31	3.11	18
7	Dryopteris affinis	F	8.96	5.35	7.16	3
8	Dryopteris filix-mas	F	6.12	5.24	5.68	9
9	Imperata cylindrica	G	2.74	3.60	3.17	11
10	Lygodium circinnatum	F	3.60	5.58	4.59	12
11	Melastoma affine	B	4.57	4.24	4.41	17
12	Mimosa pudica	B	3.16	6.49	4.83	13
13	Ottochloa nodosa	G	9.83	10.08	9.96	1
14	Oxalis barrelieri	B	5.59	4.09	4.84	10
15	Panicum repens	G	6.59	7.66	7.13	4
16	Paspalum conjugatum	G	5.27	8.09	6.68	6
17	Stachytarpheta jamaicensis	B	5.13	6.97	6.05	8
18	Synedrella nodiflora	B	3.75	4.21	3.98	15
	Average SDR		---------- 100/18 = 5.56 ----------			

Remarks: SDR = Summed dominance ratio; B = Broadleaf, G = Grass, and F = Fern

Table-2. Efficacy of paraquat and glyphosate applied in water solvent from different sources.

Herbicide (water sources)	Week after herbicide applied							
	2	4	6	8	10	12	14	16
Control (Untreated)	0.0 d	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c
Paraquat (distilled water)	92.0 a	88.0 a	79.0 ab	74.3 b	66.0 b	62.0 b	54.3 b	49.7 b
Paraquat (well water)	96.0 a	90.7 a	77.3 b	71.3 b	65.7 b	62.0 b	51.7 b	47.3 b
Paraquat (river water)	88.0 a	86.0 a	77.7 b	74.0 b	68.7 b	62.0 b	52.4 b	47.7 b
Glyphosate (distilled water)	46.0 bc	68.0 b	87.7 a	92.7 a	88.3 a	85.0 a	76.7 a	72.0 a
Glyphosate (well water)	56.0 b	61.7 b	82.0 ab	89.7 a	87.3 a	83.3 a	74.3 a	69.3 a
Glyphosate (river water)	37.3 c	58.3 b	79.7 ab	87.3 a	85.3 a	83.0 a	75.0 a	70.3 a

Remarks: Means within columns followed by the same letters are not significantly different by the LSD at $P \leq 0.05$.

respectively. Glyphosate efficacy persisted up to 16 weeks after herbicide applied (Table-2). The different water sources showed insignificant effects neither to paraquat nor to glyphosate efficacy. Glyphosate was absorbed and translocated through the phloem to the maristematic tissues (Ahrens, 1994; Duke *et al*., 2008). Therefore glyphosate efficacy appeared slow, but it killed weeds permanently. The efficacy of glyphosate were persisted very strong until 16 weeks after herbicide applied, which were 72.0, 69.3, and 70.3 percent efficacy applied in distilled, well, and river water carrier, respectively.

There were no influences of spray carrier from different sources neither to paraquat nor to glyphosate efficacy. This is likely because the water property was met to herbicide requirements including acidic pH and no turbidity which was indicated by clear and odorless water (Table-3). Paraquat and glyphosate did not ionized in acidic conditions and remained as effective materials (Thelen et al., 1995)

Table-3. Properties of water used for herbicide carrier.

Water sources	pH	Color	Odor	Turbidity
Distilled water	6.5	Very Clear	Odorless	None
Well water	5.4	Very Clear	Odorless	None
River water	5.9	Clear	Odorless	None

Remark: Analyzed in Chemical Laboratory, University of Bengkulu.

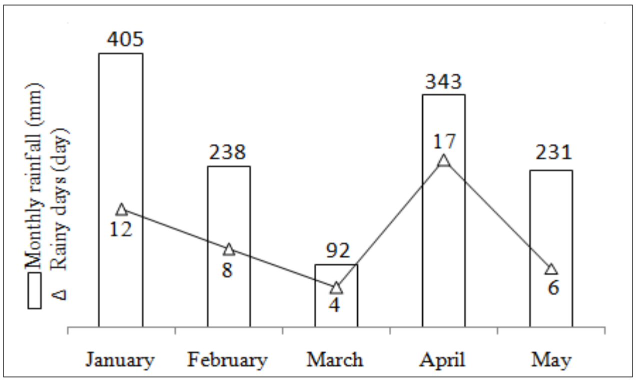

Figure-1. Montly rainfall and number of rainy days in the research location from January to May 2015.

1995; Chahal *et al.*, 2012). The climatic factors in this experiment also did not influence the paraquat and glyphosate efficacy, because montly rainfall during the experiments were in the normal distributions, except the rainfall on March which was 92 mm and 4 days of rain. At that time, herbicide treatments had been 8 weeks after aplication so that the rainfall stress did not influence paraquat and glyphosate efficacy (Figure-1).

Weeds started to grow back which was observed on weed coverages at 16 weeks after herbicide application (Table-4). The weed coverages on paraquat treatment were 23.3, 26.7 and 26.0 percent in distilled, well, and river water solutions, respectively; whereas on glyphosate treatments, the weed coverages were 8.3, 7.0, and 7.0 percent in distilled, well and river water solutions, respectively. There were no difference of the weed coverages neither on paraquat nor on glyphosate applied in three water sources, but the regrowth of weeds were higher on paraquat than and glyphosate plots.

The regrowth weeds were harvested in weed biomass at 16 weeks after herbicide application (Table-4). Dry weight of weed biomass were 17.4, 21.7, and 24.6 percent of control on paraquat treatments applied in distilled, well, and river water solutions, respectively. Weed biomass on paraquat herbicide applied in distilled water and well water solutions were slightly lower than in river water. There was no difference of weed biomass on glyphosate treatments applied in distilled, well and river water solutions, which were 5.8, 8.7, and 8.5 percent of controls, respectively.

Overall, the regrowth of weeds which observed on weed biomass were higher on paraquat than glyphosate. As a contact herbicide, paraquat destroyed the weed tissues directly but the tissues of perennial weeds including gramineae and fern groups were able to regrow (Ahrens, 1994; Monaco et al., 2002). The evolved weeds were also possible from the seed banks in the soil which germinated in favorable conditions after the treatment of contact herbicides.

Table-4. Weed coverage and dry weight biomass at 16 weeks after herbicide applied.

Herbicide (Water sources)	Weed coverage (%)	Weed biomass (%)
Control (Untreated)	100.0 a	100.0 a
Paraquat (distilled water)	23.3 b	17.4 c
Paraquat (well water)	26.7 b	21.7 c
Paraquat (river water)	26.0 b	26.4 b
Glyphosate (distilled water)	8.3 c	5.8 d
Glyphosate (well water)	7.0 c	8.7 d
Glyphosate (river water)	7.0 c	8.5 d

Remarks: Means within column followed by the same letters are not significantly different by the LSD at $P \leq 0.05$. Dry weight of weed biomass of control = 203.3 gram m^{-2}.

On the other circumstances, glyphosate activity was effective after absorbed and translocated to the maristematic tissues, therefore glyphosate molecules can kill the whole body of weeds. The regrowth weeds in glyphosate plots were possible from the seed bank in the soil (Chahal et al., 2012). Overall, the different sources of water carriers either with paraquat or glyphosat showed nonsignificant effect to weed coverage and weed biomass.

Weed analysis showed that the number of weeds species decreased from 18 into 13 species due to herbicide application (Table-5). Weed communities shifted and decreased in oil palm plantation due to herbicide treatments (Wibawa et al., 2009). Five weed species that escaped after paraquat and glyphosate application were Ageratum conyzoides, Digitaria sanguinalis, Dryopteris filix-mas, Mimosa pudica, and Synedrella nodiflora. The escaped weeds indicated that paraquat and glyphosate were very effective to control these species.

Some weeds performed tolerant to herbicide treatments which were indicated by regrowth ability. Regrowth ability of weed which was indicated by SDR_1 was higher on paraquat treatments compared to glyphosate (Table-5). Some weed species were capable to grow back after paraquat applied in distilled water solutions were Paspalum conjugatum, Ottochloa nodosa with the SDR_1 6.0 dan 5.1, respectively; paraquat applied in well water were Ottochloa nodosa, Panicum repens, Paspalum conjugatum, Oxalis borrelieri with the SDR_1 5.5, 3.6, 3.2, dan 2.4, respectively; and paraquat applied in river water were Paspalum conjugatum, Ottochloa nodosa, Cyclosorus aridus, and Borreria latifolia with the SDR_1 5.8, 4.8, 2.2, and 2.0, respectively.

At the end of the experiment, growing weeds in the herbicide trials were determined by SDR_1. Glyphosate was effective to control grass, broadleaf, and fern weeds indicated by the very low value of SDR_1 in the glyphosate treatments using distilled, well and river water for herbicide carrier. Glyphosate is a systemic and broad spectrum herbicide, the mode of action inhibit EPSPS enzyme in biosynthesis of three amino acids including tryptophan, tyrosine, and phenylalanine (Ahrens, 1994). The least possibility of herbicide resistant weeds was currently reported on glyphosate (Duke et al., 2008).

Paraquat performed a strong efficacy from 2 to 3 weeks after application, but at 16 weeks after applied showed that some weed species were able to grow back, such as Paspalum conjugatum (grass), Ottochloa nodosa (grass), Panicum repens (grass), Cyclosorus aridus (fern), and Borreria latifolia (boadleaf). Three weeds were grassess, and one was each fern and broadleaf groups. The regrowth of grass and fern weeds was because of vegetative parts of these perennial weeds such as root, stolon, and rhizomes that were not completely killed and able to regenerate, while the regrowth of broadleaf weeds were probably from the new germination of seed banks in the soil (Monaco et al., 2002). The tolerance of the grass and fern weeds to paraquat caused the ineffectiveness of weed control using contact herbicides such as paraquat.

4. CONCLUSIONS

Nine dominant weeds in oil palm plantations in Bengkulu, Indonesia are Ottocloa nodosa, Cyclosorus aridus, Dryopteris affinis, Panicum repens, Axonopus compressus, Paspalum conjugatum, Borreria latifiola, and Stachytarpheta jamaicensis, and Dryopteris filix-mas. A very strong efficacy of paraquat and glyphosate were observed at 2 and 8 weeks after application, respectively, while the efficacy of paraquat and glyphosate persisted to 8 and 16 weeks, respectively. Some weeds evolved tolerant to paraquat were Paspalum conjugatum (grass), Ottochloa nodosa (grass), Panicum repens (grass), Cyclosorus aridus (fern), and Borreria latifolia (broadleaf). Distilled, well, and river water used for herbicide carrier did not influence neither paraquat nor glyphosate efficacy.

Table-5. Weed analysis in the oil palm plantation at 16 weeks after herbicide applied.

No.	Weed species	(0)	SDR_1 (SDR x Weed Coverage)					
			(1)	(2)	(3)	(4)	(5)	(6)
1	Ageratum conyzoides (B)	3.59	-	-	-	-	-	-
2	Axonopus compressus (G)	6.76	1.1	1.3	1.3	0.4	0.3	0.4
3	Borreria latifiola (B)	6.30	1.5	1.7	2.0	0.5	0.4	0.5
4	Cyclosorus aridus (F)	7.63	1.0	1.7	2.2	0.7	0.7	0.6
5	Cyperus kyllingia (G)	4.18	0.8	1.1	1.0	0.7	0.4	0.4
6	Digitaria sanguinalis (G)	3.11	-	-	-	-	-	-
7	Dryopteris affinis (F)	7.16	0.8	1.1	1.1	0.5	0.4	0.4
8	Dryopteris filix- mas (F)	5.68	-	-	-	-	-	-
9	Imperata cylindrica (G)	4.83	1.1	1.2	1.2	0.4	0.4	0.4
10	Lygodium circinnatum (F)	4.59	1.2	1.3	1.2	1.1	0.5	0.7
11	Melastoma affine (B)	3.17	1.1	1.3	0.9	0.4	0.4	0.4
12	Mimosa pudica (B)	4.41	-	-	-	-	-	-
13	Ottochloa nodosa (G)	9.91	5.1	5.5	4.8	1.3	1.7	1.0
14	Oxalis barrelieri (B)	4.84	1.3	2.4	1.3	0,5	0.3	0.4
15	Panicum repens (G)	7.13	1.0	3.6	1.6	0.5	0.3	0.4
16	Paspalum conjugatum (G)	6.68	6.0	3.1	5.8	0.7	0.7	1.2
17	Stachytarpheta jamaicensis (B)	6.05	1.4	1.4	1.6	0.4	0.4	0.4
18	Synedrella nodiflora (B)	3.98	-	-	-	-	-	-
	T o t a l	100	23.3	26.7	26.0	8.3	7.0	7.0

Remarks: (0) = SDR of Control plots; (1), (2), and (3) = paraquat applied in distilled, well, and river water solutions, respectively; (4), (5), and (6) = glyphosate applied in distilled, well, and river water solutions, respectively

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