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Research Article

Weed diversity as affected by tillage and ammonium glufosinate herbicide[1]

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ABSTRACT

Farmers in Indonesia generally spray herbicides to control weeds and use tillage during the early stages of crop cultivation; consequently, these activities affect the weed composition and diversity. This study aimed to evaluate the dominance and diversity index of weeds and obtain abundance correlations according to the soil chemical characteristics, as well as the effect of the ammonium glufosinate herbicide, in different tillage systems. A non-factorial randomized block design was used, consisting of no-tillage (NT), 1-time tillage (T1) and 2-times tillage (T2), with three replications. The *Cyperus rotundus* and *Ageratum conyzoides* weed species were dominant in the tillages. The diversity indices were 2.261, 2.196 and 2.234 (moderate/stable condition), respectively for the NT, T1 and T2. For T2, there were increases of 2.82-folds, 41 populations and 2.43-folds, respectively for *A. conyzoides*, *Cynodon dactylon* and *Euphorbia heterophylla*, when compared to NT, while a decrease was observed in grasses for T1 and T2 (50.71 and 26.05 %, respectively). Moreover, there was a positive and significant correlation for *E. heterophylla* according to the soil cation exchange capacity (0.727). In contrast, four new weed species (*Glyceria maxima*, *Leersia oryzoides*, *Scoparia dulcis* and *Anthoxanthum oculatum*) were found due to the ammonium glufosinate application, in the different tillage systems.

KEYWORDS: Grasses, broadleaf weeds, sedges, weed abundance.

RESUMO

Diversidade de plantas daninhas em função do preparo do solo e da aplicação do herbicida glufosinato de amônio

Na Indonésia, os agricultores geralmente pulverizam herbicidas para controlar plantas daninhas e revolvem o solo durante as fases iniciais de cultivo; consequentemente, essas atividades afetam a composição e a diversidade das plantas daninhas. Objetivou-se avaliar a dominância e o índice de diversidade de plantas daninhas e obter correlações de abundância considerando-se as características químicas do solo, bem como o efeito do herbicida glufosinato de amônio, em diferentes sistemas de preparo do solo. Utilizou-se delineamento não-fatorial em blocos casualizados, consistindo de não revolvimento (NR), um revolvimento (R1) e dois revolvimentos (R2) do solo, com três repetições. As espécies *Cyperus rotundus* e *Ageratum conyzoides* foram dominantes nos revolvimentos. Os índices de diversidade foram de 2,261; 2,196; e 2,234 (condição moderada/estável), respectivamente para o NR, R1 e R2. Para o R2, houve aumento de 2,82 vezes, 41 populações e 2,43 vezes, respectivamente para *A. conyzoides*, *Cynodon dactylon* e *Euphorbia heterophylla*, em comparação com o NR, enquanto uma diminuição foi observada nas gramíneas para R1 e R2 (50,71 e 26,05 %, respectivamente). Além disso, houve correlação positiva e significativa para *E. heterophylla* em função da capacidade de troca catiônica do solo (0,727). Em contraste, foram encontradas quatro novas espécies de planta daninha (*Glyceria maxima*, *Leersia oryzoides*, *Scoparia dulcis* e *Anthoxanthum oculatum*) em resposta à aplicação de glufosinato de amônio, nos diferentes sistemas de preparo.

PALAVRAS-CHAVE: Gramíneas daninhas, plantas daninhas de folhas largas, ciperáceas, abundância de plantas daninhas.

INTRODUCTION

Uncontrolled weeds on farmlands reduce yield up to 80 % (Cousens & Mortimer 1995). Therefore, sustainable agricultural practices affect its abundance and density. The weed abundance in the farmland is influenced by several factors, such as seed bank buried in the soil (Norris 2007), environmental factors

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(Fried et al. 2008, Pinke et al. 2012), availability of nutrients and fertilization (Murphy & Lemerle 2006, Cheimona et al. 2016), tillage and crop rotation (Ulber et al. 2009, Nichols et al. 2015), and weed control using herbicides (Derksen et al. 1995).

Farmers in Indonesia generally spray herbicides to control weeds and use tillage during the early stages of crop cultivation; consequently, these activities affect the weed composition and diversity. Menalled et al. (2001) showed that different agricultural management systems significantly affect weed abundance, diversity and consistency in the short and long term (6 years). Meanwhile, Derksen et al. (1995) reported that the germination of *Synapsis avensis* and *Brassica napus* weeds after spraying with herbicides was higher in the no-tillage, but there was a reduction in total weeds. Thomas et al. (2004) also reported that perennial weed species such as *Cirsium arvense* and *Sonchus arvensis* were reduced by tillage and no-tillage (100 and 28.21 %, respectively), while annual weeds were found in various tillage treatments. In addition, Trichard et al. (2013) stated that tillage favors the weed seed bank germination and causes the extinction of other seeds.

On the other hand, different soil fertility levels in the planted area also affect the weed diversity (Yin et al. 2006). Fonge et al. (2013) reported that weed diversity is affected by soil organic-C content, nitrogen, calcium and cation exchange capacity. Tang et al. (2014a) added that phosphorus + potassium (PK) fertilization increases the density of *Galium aparine*, *Vicia sativa*, *Veronica persica* and *Geranium carolinianum*, when compared to nitrogen + phosphorus (NP). Furthermore, Forcella et al. (2000) stated that the soil N concentration plays an important role in ending dormancy by removing germination constraints and stimulating seedling emergence. Tang et al. (2014b) reported that soil available-P is the primary nutrient, regulating the composition of weed species and diversity, followed by N and K.

The knowledge of farmers on the relationship between tillage and soil fertility status with weed diversity is relatively poor. Interviews conducted in this study showed that the farmers only carry out land clearing and manual tillage before planting, had never used herbicides, and unknowingly the soil fertility status. However, a new problem was found: weed growth was very fast in a short time (2 days). Therefore, intensive control during one main crop cycle is highly needed. This problem persisted during crop rotation. Unnoticed by farmers, these activities impact the storage of the weed seed bank and the tillage carried out, resulting in the weed seed bank at a certain depth of soil emerging to the soil surface.

Studies on weed identification are needed to provide information on the relationship between soil fertility on the dominant weeds and the use of one herbicide with a recommended dose to suppress the presence of weeds. Therefore, this study aimed to evaluate the dominance and diversity index of weeds and obtain correlations of weed abundance on soil chemical characteristics, as well as the effect of the ammonium glufosinate herbicide on weed abundance, in different tillage systems.

MATERIAL AND METHODS

This study was carried out on farmland in Padang Bulan, Medan Selayang subdistrict, Medan, Indonesia (3º33.753'N, 98º38.890'E and altitude of 15 m a.s.l.), from March to July 2021, in Inceptisols (GMCG 2022). This is an area with continuous land use and a history of crop rotation for the last two years with corn, cucumber and cowpea, as well as manual tillage using hoe, without the use of herbicides, based on interviews with farmers.

A non-factorial randomized block design, with three replications, was used: no-tillage, 1-time tillage and 2-times tillage. The land was cleared and then plotted with the square method of 1 m × 1 m and spacing of 2 m between plots. Each plot was demarcated with plastic ropes with a distance of 0.2 m between rows.

Tillage was carried out by hoeing as deep as 20 cm. Meanwhile, the land was incubated for a month and then identified for weed vegetation using the flora book and applying formulas according to Kent (2012), such as absolute density (number of individual weed species in the sample plot), relative density [(absolute density of a certain species)/(total absolute density of all species) × 100 %], absolute frequency (number of sample plots containing certain species), relative frequency [(absolute frequency of a certain species)/(total absolute frequencies of all species) × 100 %], importance value (relative density + relative frequency) and summed dominance ratio [(relative density + relative frequency)/2].

The weed populations based on morphology (broadleaf, grasses and sedges) and total weeds were also calculated. The species diversity index was calculated using the Shannon-Wiener index formula (Shannon & Weaver 1949):

$$H' = -\sum_{n=1}^{n} \left(\frac{ni}{N}\right)\left(\ln \frac{ni}{N}\right)$$

where: H' is the species diversity index; ni the proportion of species *I*; N the total number of species; and ln the natural logarithm.

The classification of the diversity index value for each tillage was conducted based on Magurran (1988), who stated that it is low if $H' < 1$, moderate if $1 < H' < 3$ and high if $H' > 3$. Soil samples at a depth of 0-20 cm were taken using a drill, with a diagonal method on each plot. Then, analysis was performed on organic-C (Walkley & Black method) and cation exchange capacity - CEC (ammonium acetate pH 7), using a spectrophotometer (Socfin Indonesia Inc., Medan, Indonesia). At first, a natural logarithm was carried out on the organic-C, CEC data and total of dominant weeds, as well as using the Pearson's correlation.

The ammonium glufosinate herbicide was applied on Apr. 27 (2021) at 10.00 a.m. to the plots of all tillage systems [no-tillage (NT), 1-time tillage (T1) and 2-times tillage (T2)], at a dose of 150 g a.i. ha^{-1}, after a spray calibration was carried out. The climatic data were recorded during spraying (temperature of 28 ºC, humidity of 83 % and air pressure of 1,002 hPa). The weed survival data were measured at 6 weeks after spraying. The spraying was carried out using a manual spray equipment (Solo Model) with operating pressure and application volume of 2 kg cm^{-2} and 202.90 L ha^{-1}, respetively. Weeds with height up to 60 cm were sprayed. The data of weeds (broadleaf, grasses, sedges and total) and soil (organic-C and CEC) were processed with Anova, followed by DMRT at $p < 0.05$ using the IBM SPSS v.20 software.

RESULTS AND DISCUSSION

The field observations obtained 16 species (*Ageratum conyzoides*, *Asystasia gangetica*, *Axonopus compressus*, *Borreria alata*, *Brachiaria mutica*, *Cleome rutidosperma*, *Cynodon dactylon*, *Cyperus rotundus*, *Eleusine indica*, *Euphorbia heterophylla*, *Galinsoga parviflora*, *Mimosa pudica*, *Oxalis corniculata*, *Pennisetum purpureum*, *Polanisia icosandra* and *Stylochaeton lancifolius*), with 6,639 populations from three tillage systems (NT, T1 and T2) (Figure 1). The results showed that three dynamic patterns due to tillage, such as an increase in the weed diversity due to 2-times tillage for *A. conyzoides*, *C. dactylon* and *E. heterophylla*; a decrease in weed diversity due to 2-times tillage for *A. gangetica*, *A. compressus*, *B. alata*, *C. rutidosperma* and *E. indica*; and a fluctuating pattern, indicating a decrease in weed species in the 1-time tillage and then an increase in the 2-times tillage, or vice versa, for *B. mutica*, *G. parviflora*, *M. pudica*, *O. corniculata*, *P. purpureum*, *P. icosandra* and *S. lancifolius*.

The tillage had an insignificant effect on the number of broadleaf, grasses, sedges and total weeds (Figure 2). However, the increasing of tillage by 2-times (T2) also increased the broadleaf population and total weeds by 41.73 and 25.19 %, respectively, when compared to no-tillage (NT). Furthermore, the population of sedges increased at 1-time tillage

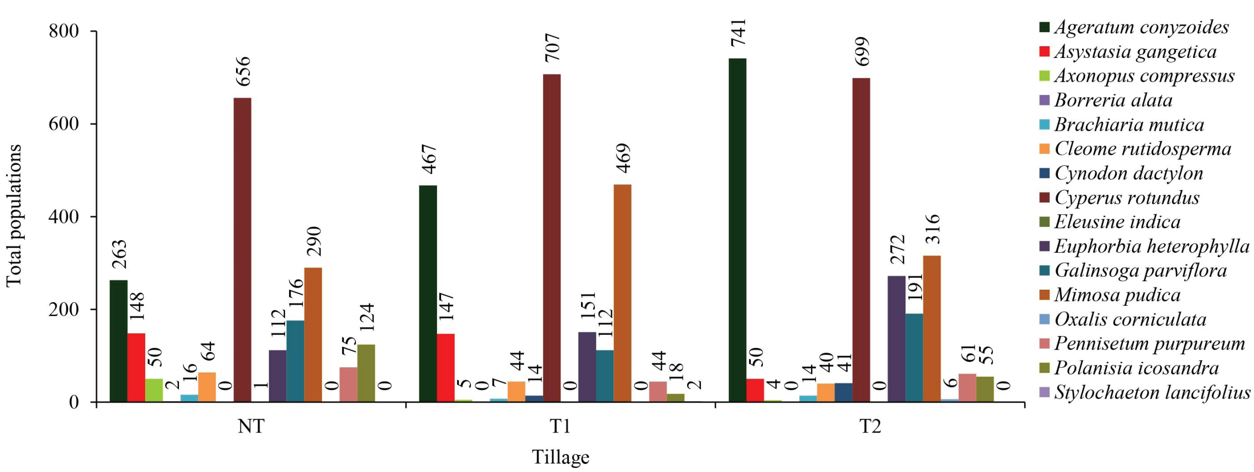

Figure 1. Total populations of weeds due to tillage (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage).

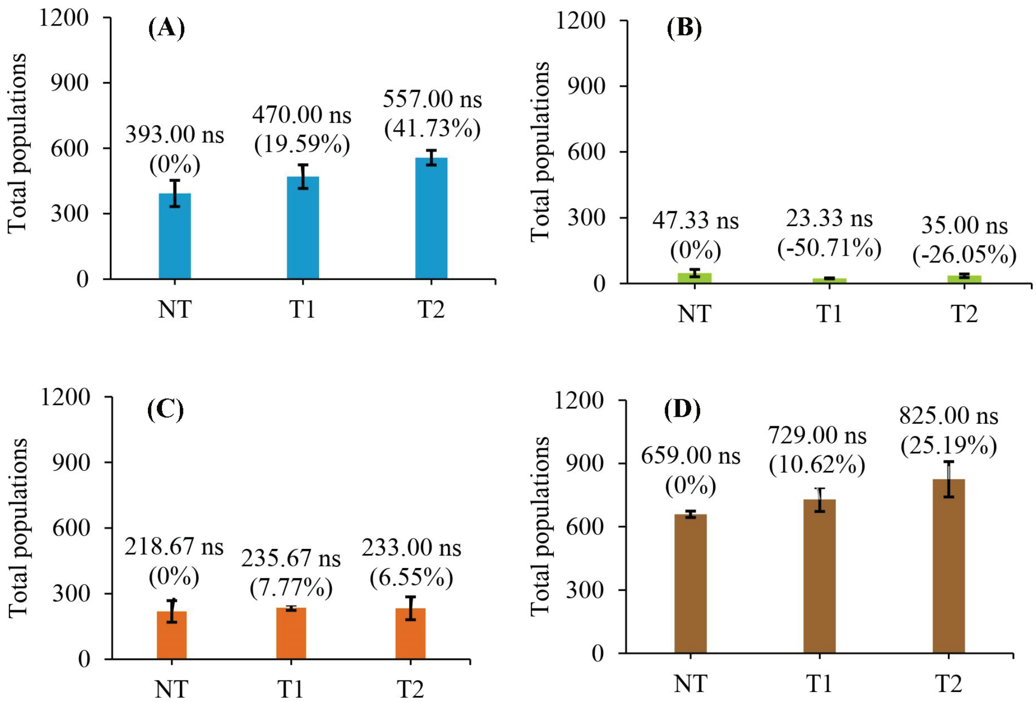

Figure 2. Weed populations based on morphology (A: broadleaf; B: grasses; C: sedges) and total weeds (D) due to tillage (NT: no tillage; T1: 1-time tillage; T2: 2-times tillage). Values followed by "ns" are not significantly different at the 5 % level, based on the DMRT. The vertical line shows the standard error.

(T1) by 7.77 %, if compared to NT, and decreased to 6.55 % at 2-times tillage (T2). The population of grasses experienced the highest decrease in the 1-time tillage (T1) of 50.71 %, when compared to NT.

The summed dominance ratio (SDR) and diversity index due to tillage are presented in Figure 3 and Table 1. In the no-tillage (NT) treatment, five species with the highest SDR were sequentially found (*C. rotundus*, *M. pudica*, *A. conyzoides*, *C. rutidosperma* and *P. icosandra*), with 22.78, 13.37, 12.50, 10.90 and 10.49 %, respectively. For the 1-time tillage (T1), five species with the highest SDR were sequentially found (*C. rotundus*, *M. pudica*, *A. conyzoides*, *A. gangetica* and *E. heterophylla*), with 22.61, 16.42, 16.41, 10.87 and 9.63 %, respectively. Moreover, in the 2-times tillage (T2), five species with the highest SDR were also sequentially found (*A. conyzoides*, *C. rotundus*, *M. pudica*, *E. heterophylla* and *G. parviflora*), with 22.20, 18.76, 12.67, 11.36 and 9.90 %, respectively. The diversity index (H') due to tillage (NT, T1 and T2) were 2.261, 2.196 and 2.234, respectively; therefore, it was moderate.

The tillage significantly increased the cation exchange capacity (CEC), but it had an insignificant effect on the soil organic-C (Figure 4). There was an increase in the CEC due to T1 and T2 by 16.56 and 13.14 %, respectively. The correlation analysis of soil organic-C and CEC on the dominant weed population due to tillage is presented in Table 2. The results showed that only CEC had a significant and positive correlation in increasing *E. heterophylla* by 0.727, but it was insignificant for *C. rotundus* and *C. rutidosperma*. Similarly, the soil organic-C had an insignificant effect, but was positively correlated to the populations of *C. rotundus*, *A. conyzoides*, *M. pudica* and *E. heterophylla*.

Changes in weed vegetation due to ammonium glufosinate application at a dose of 150 g a.i. ha^{-1} on different tillage systems (NT, T1 and T2) by species are presented in Figure 5. The results showed an increase for *B. alata* and *B. mutica* due to the ammonium glufosinate in the NT and 2-times tillage (T2). Meanwhile, others decreased, and two new weed species were found in the NT (*Glyceria maxima* and *Leersia oryzoides*) and one new weed species was found in the T2 (*G. maxima*). Similarly, the 1-time tillage (T1) increased *B. alata*, *B. mutica* and *E. indica*. At the same time, other populations decreased, and four new weed species were found:

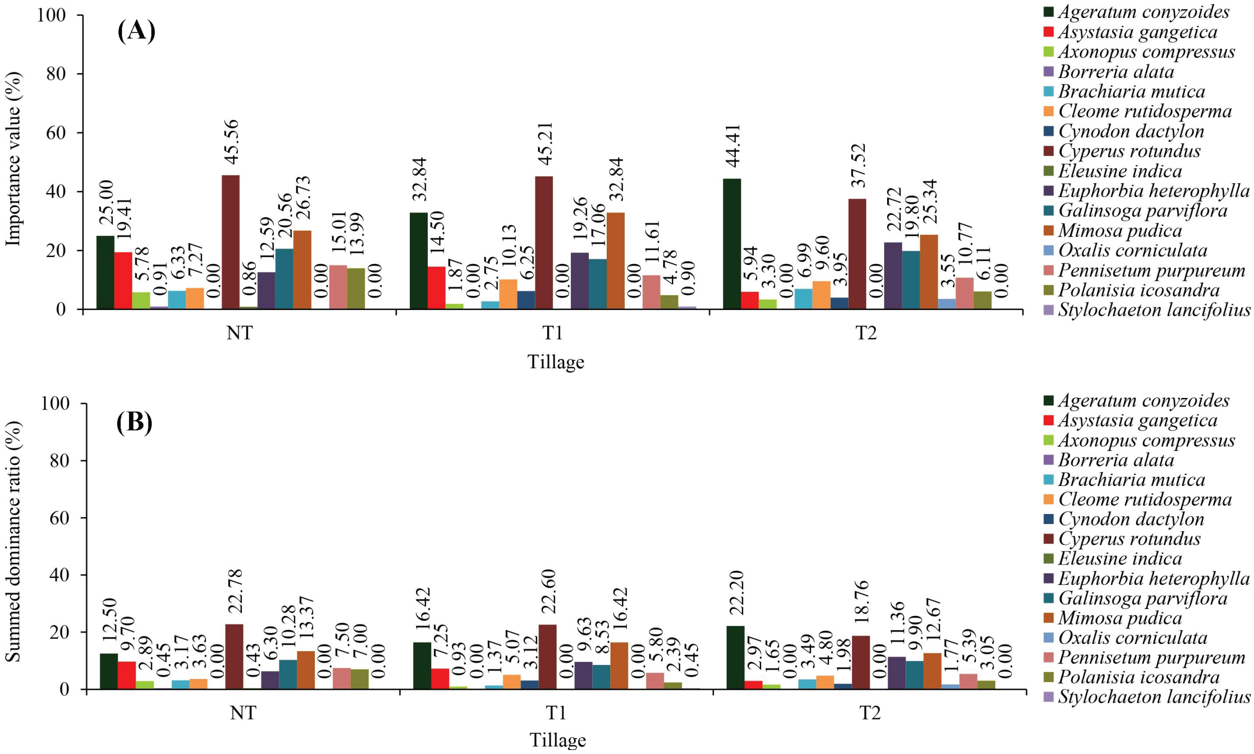

Figure 3. Importance value (A) and summed dominance ratio (B) of weeds due to tillage (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage).

Table 1. Diversity index of weeds due to tillage (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage; H': species diversity index).

Family	Weeds species	H'		
		NT	T1	T2
Asteraceae	*Ageratum conyzoides*	0.260	0.297	0.334
	Galinsoga parviflora	0.234	0.210	0.229
Acanthaceae	*Asystasia gangetica*	0.226	0.190	0.104
Araceae	*Stylochaeton lancifolius*	-	0.024	-
Capparaceae	*Cleome rutidosperma*	0.120	0.151	0.146
Capparidaceae	*Polanisia icosandra*	0.186	0.089	0.107
Cyperaceae	*Cyperus rotundus*	0.337	0.336	0.314
Euphorbiaceae	*Euphorbia heterophylla*	0.174	0.225	0.247
Fabaceae	*Mimosa pudica*	0.269	0.297	0.262
Oxalidaceae	*Oxalis corniculata*	-	-	0.072
Poaceae	*Axonopus compressus*	0.102	0.044	0.068
	Brachiaria mutica	0.109	0.059	0.117
	Cynodon dactylon	-	0.108	0.078
	Eleusine indica	0.023	-	-
	Pennisetum purpureum	0.194	0.165	0.157
Rubiaceae	*Borreria alata*	0.024	-	-
Total		2.261	2.196	2.234

G. maxima, *L. oryzoides*, *Scoparia dulcis* and *Anthoxanthum oculatum*.

Based on morphology, the effectiveness of ammonium glufosinate on the weed-type abundance at different tillage systems (NT, T1 and T2) is presented in Figure 6. The herbicide application can decrease the abundance of broadleaf weeds by 82.13-84.98 % and sedges by 8.15-19.05 %. However, there

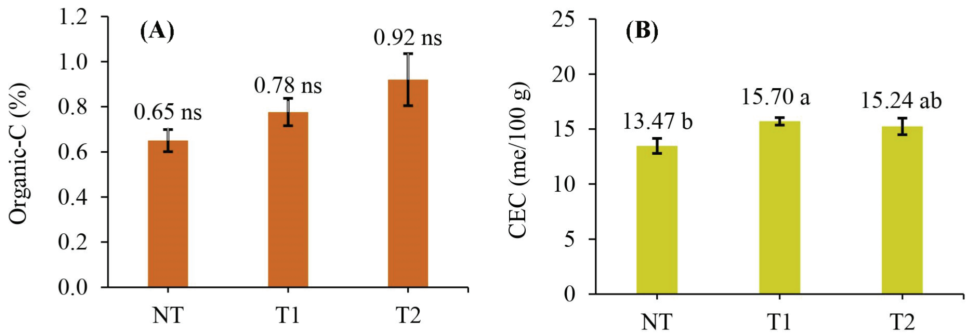

Figure 4. Soil organic-C (A) and cation exchange capacity (CEC) (B) properties due to tillage (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage). Values followed by different letters in the graph are significantly different at the 5 % level based on the DMRT. The vertical line shows the standard error. ns: not significant.

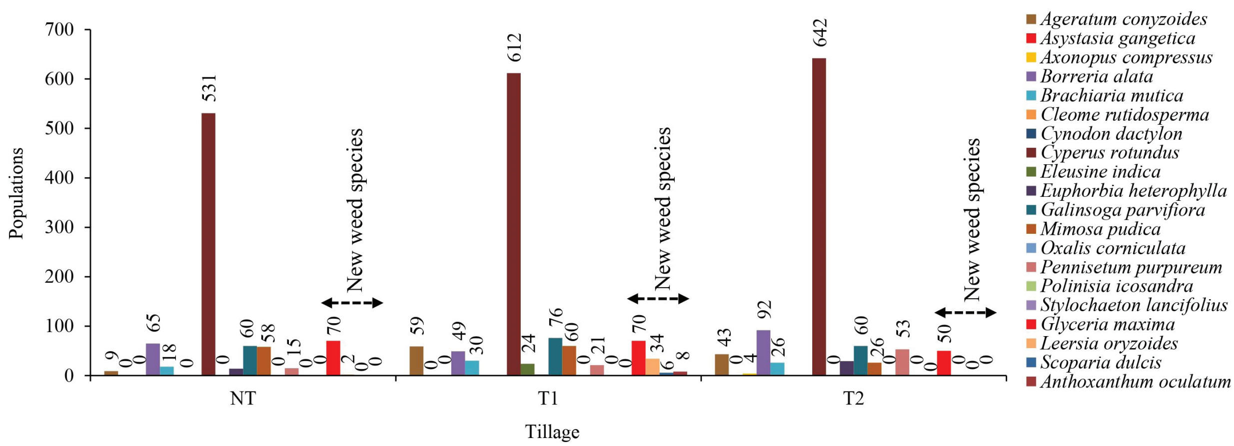

Figure 5. Changes in weed vegetation due to ammonium glufosinate application at a dose of 150 g a.i. ha^{-1} on different tillage systems (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage).

Table 2. Correlation analysis of soil organic-C (%) and cation exchange capacity (CEC) on the dominant weed populations due to tillage.

Dominant weed species	Correlation coefficient	
	Organic-C (%)	CEC (me 100 g^{-1})
Cyperus rotundus	0.449^{ns}	0.262^{ns}
Ageratum conyzoides	0.132^{ns}	-0.154^{ns}
Mimosa pudica	0.147^{ns}	-0.054^{ns}
Euphorbia heterophylla	0.127^{ns}	0.727*
Galinsoga parviflora	-0.063^{ns}	-0.240^{ns}
Asystasia gangetica	-0.298^{ns}	-0.482^{ns}
Polanisia icosandra	-0.021^{ns}	-0.646^{ns}
Cleome rutidosperma	-0.095^{ns}	0.591^{ns}

* Correlation is significant at the 0.05 level (2-tailed). ^{ns} not significant.

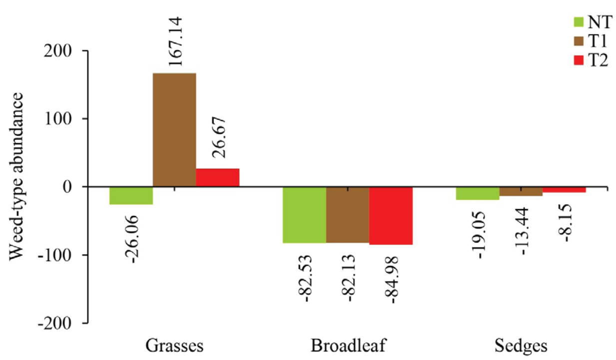

Figure 6. Effectiveness of ammonium glufosinate on the weed-type abundance at different tillage systems (NT: no-tillage; T1: 1-time tillage; T2: 2-times tillage).

was an increase in the grass weeds abundance in the T1 and T2 by 167.74 and 26.67 %, respectively.

Based on the results, there were three dynamic patterns of weed diversity due to tillage, namely increasing, decreasing and fluctuating patterns. The increasing weed species due to 2-times tillage (T2) include *A. conyzoides* (2.82-folds), *C. dactylon* (41 populations) and *E. heterophylla* (2.43-folds), when compared to no-tillage (NT). It was caused by the seed banks of *A. conyzoides*, *C. dactylon* and *E. heterophylla* during T2, which triggered the emergence to the soil surface. Furthermore, the soil fertility also supported its growth faster. This was supported by the organic-C, which was positively correlated with the presence of *A. conyzoides* (0.132) and *E. heterophylla* (0.127). Besides, the soil CEC was also significantly and positively correlated with the presence of *E. heterophylla* (0.727) (Table 2). These results are similar to those by Oziegbe et al. (2010), who observed that active weed seed banks at deeper soil depths lead to lower oxygen availability and reduce the access to the light required to support germination. In addition, Hossain et al. (2021) found that the seed bank of *A. conyzoides* was not found at a depth of 0-10 cm, but at 10-15 cm, and experienced an additional seed bank of 43.82 % during conventional tillage. Horowitz (1972) reported that 88 % of *C. dactylon* rhizomes were found at a depth of 30 cm. Ekeleme et al. (2019) added that *E. heterophylla* had the second-highest abundance (19.53 %) after *Tridax procumbens* in Benue state, Nigeria.

The results showed that *C. rotundus* had the highest SDR in the NT and T1, while *A. conyzoides* was dominant in T2. This was due to the presence of higher seed banks of *C. rotundus* and *A. conyzoides* at certain depths. Therefore, when the soil is tilled, the seed banks trigger emergence on the soil surface. These results are similar to those by Hossain et al. (2021), who reported that up to 24 % of the *C. rotundus* seed bank were found at a depth of 5-10 cm, while 21 % of the *A. conyzoides* were found between 10 and 15 cm. Furthermore, Santín-Montanyá et al. (2013) reported that the weed abundance, diversity and evenness were greatly increased in the no-tillage treatment. In this study, the results showed that the diversity index due to tillage (NT, T1 and T2) was, respectively, 2.261, 2.196 and 2.234 (moderate) (Table 1). The decrease in diversity index due to T1 and T2, when compared to NT, indicates that tillage decreases the weed diversity. Mas & Verdú (2003) reported that the highest value for the Shannon-Wiener diversity index was found in the no-tillage treatment, while Amuri et al. (2010) suggested that the no-tillage treatment contributes to the suppression of several weed species. Sepat et al. (2017) also reported that the lowest weed population was found in untilled beds.

The results showed that T2 increased the broadleaf and total weeds. The population of sedges increased at T1, but decreased during T2. In general, only grasses decreased during T1 and T2, in relation to NT, and the highest decrease was found at T1. This is linear with the Shannon-Wiener diversity index at T1, lower than other tillage systems (Table 1). These results are supported by Murphy et al. (2006), who reported that the weed density is only affected by tillage. Similarly, Hossain et al. (2021) observed a decrease in the seed bank of grasses during conventional tillage by 76.31 %, at a depth of 0-5 cm, if compared to no-tillage.

The cation exchange capacity (CEC) was significantly and positively correlated (0.727), with an increase in the population of *E. heterophylla*. The contents of CEC and organic-C were also positively correlated, but had an insignificant effect on the populations of *C. rotundus*, *C. rutidosperma*, *A. conyzoides* and *M. pudica*. This was due to the higher content of CEC and organic-C in T1 and T2, in relation to NT (Figure 4). When the weed seed bank at T1 and T2 emerged to the surface and received more light and soil fertility than the NT, it tended to support the growth of more weeds, as indicated in the total weed population, which grows higher with increasing tillage (Figure 2). These results are similar to those by Pätzold et al. (2020), who reported that soil organic-C affects weed species variability by 8.4 %; while Gaston et al. (2001), Nordmeyer & Häusler (2004) and Korres et al. (2017) reported that soil organic carbon, texture and nutrients affect the emergence of weeds. Furthermore, Dorneles et al. (2015) reported that the reduced tillage had a higher CEC than the no-tillage at 0-5 cm and 5-10 cm depths.

There was an increase in the populations of *B. alata* (49), *B. mutica* (30) and *E. indica* (24) after spraying the ammonium glufosinate herbicide at a dose of 150 g a.i. ha^{-1} with different tillage systems (NT, T1 and T2), although *C. rotundus* (612) was more numerous than the other weeds. Four new weed species, namely *G. maxima*, *L. oryzoides*, *S. dulcis* and *A. oculatum*, were found in NT, T1 and T2 due to the ammonium glufosinate herbicide. *Glyceria maxima* is a new weed species with the highest population in the NT, T1 and T2 tillage systems. Furthermore, the increase in population and new weed species was higher in the grasses (*B. mutica*, *E. indica*, *G. maxima*, *L. oryzoides* and *A. oculatum*) and two new species from the broadleaf weeds (*B. alata* and *S. dulcis*). Therefore, the ammonium glufosinate herbicide at different tillages decreased the abundance of broadleaf weeds (Figure 6), in relation to the grasses.

Using herbicides on tillage (T1 and T2) exposed the seed bank of grasses to the soil surface to adequately obtain oxygen and light needed for growth. This is supported by Wibawa et al. (2009), who reported that the herbicide at a dose of 200 g ha^{-1} significantly suppressed broadleaf weeds by 94.68 %, when compared to grasses (59.65 %), at two weeks after spraying. Tampubolon et al. (2019) also found that the ammonium glufosinate herbicide at a dose of 300 g a.i. ha^{-1} significantly removed 100 % of the glyphosate-susceptible *E. indica*, while Alridiwirsah et al. (2020) reported that the grasses were 52.76 % higher, if compared to broadleaf and sedges in guava plants. In addition, Głowacka (2011) stated that the number of *Echinochloa crus-galli* (grasses) was more dominant with mechanical control (18.0 populations) and herbicides (10.3 populations) in maize plants, when compared to other weeds, including *G. parviflora*, *Chenopodium album*, *Cirsium arvense* and *Polygonum lapathifolium*. Uddin et al. (2018) also added that the abundance of grasses was 130.1 % higher than broadleaf weeds (108.5 %) and sedges (61.4 %), in the rice and potato cropping pattern.

Based on these findings, it is recommended to spray ammonium glufosinate during land clearing to decrease the broadleaf and sedge weeds abundance, and then apply 1-time tillage (T1) to decrease the population of grass weeds.

CONCLUSIONS

1. The 2-times tillage (T2) system increased the *Ageratum conyzoides* (2.81-folds), *Cynodon dactylon* (41 population) and *Euphorbia heterophylla* (2.43-folds) populations, when compared to the no-tillage (NT) system;
2. *Cyperus rotundus* had the highest summed dominance ratio at NT and 1-time tillage (T1), while *A. conyzoides* was found in T2 with a moderate diversity index;
3. Based on the classification, only grasses decreased in T1 and T2. Furthermore, there was a significant and positive correlation between *E. heterophylla* and cation exchange capacity (0.727);
4. A total of four new weed species, namely *Glyceria maxima*, *Leersia oryzoides*, *Scoparia dulcis* and *Anthoxanthum oculatum*, were found for NT, T1 and T2, due to the application of the ammonium glufosinate herbicide.

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