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Herbicide Resistance: A Challenge For Sustainable Agriculture*)

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ABSTRACT

Herbicide, in modern agriculture, plays an important role in increasing agricultural production.In Indonesia, oil palm field is the is the highest volume of herbicide usage. The herbicide is generally applied three to four rounds each year. Persistent use of the same mode of action of for a long time of period could lead to the development herbicide-resistance in weed biotype or succession of dominant weed species. The occurrenceof a herbicide resistant weed population will make its control more difficult and creates more cost. Similarly, weed management problems may also occur when dominant weed species shift from dominant weed species easy to control to weed species more difficult to control. Both of these consequences, herbicide resistance and weed succession, are due to persistent use of the same mode of action of herbicide for a long time of period which results in weed control failures. Herbicide resistant weed population and weed species succession should be overcome or delayed by implementing integrated weed management or diversity of herbicides.

Keywords: *herbicide-resistance, mode of action, evolution, resistance management, persistent.*

Introduction

Herbicide has been used since the invention of chemical for weed control in 1940s. The herbicide has contributed significantly in the increase of agricultural production. Since the discovery of modern herbicides (2,4-D and MCPA) in 1940s herbicide has been playing an important role in modern agriculture to significantly increase agricultural production. Herbicide usage makes weed control much easier and quicker and cheaper compared to conventional method odf weed control. Herbicide usage is often more reliable and least expensive method of weed control available, and its success is largely responsible for food production support world population, include palm oil, which continually increase. The efficacy and cost effectiveness of herbicides for weed control has led to heavy reliance on herbicides in agricultural production (Heap and LeBaron, 2001). However, repeated use the same of herbicide or the same mode of action of herbicide is not without consequency (Powles and Yu, 2010).Using the same mode of action of herbicide for a long time will lead to a selection pressure and forms herbicide resistant population (Pieterse, 2008). Integrated program in weed management practices should be implemented to avoid or delay the development of resistant weeds.

Oil palm is the most important perennial crops in Indonesiaand Malaysia. The two countries are the most important oil palm producing countries in the world which produce 85% of total world oil palm production (http://www.indexmundi.com). Today, million hectares of land in Malaysia is under oil palm cultivation(http://www.mpoc.org.my,2016).

Moreoverin Indonesia, oil palm has been cultivated in more than eleven million hectares in 2015 which makes Indonesia to become the largest oil palm area in the world(BPS, 2015). Approximately 6.3 million hectares (62.5%) were found in Sumatra of which is about 1.2 million ha located in North Sumatra.

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Weed control expenditure is one of important cost productions in oil palm plantations. Cost of weed control in oil palm plantations is ranging from 17 to 27% of total maintenance costs ofoil palm (Azahariet al.2004). There are a number of common weeds , broadleaves and grasses, grow in oil palm area. Asystasia (*Asystasiaintrusa*) and goosegrass (*Eleusineindica*) are two species of weeds which are often found in oil palm plantations (Chung, 2000) and appeared to be more problems lately. This paper aims to discuss on the role of herbicide in oil palm plantation, how herbicides evolve resistance and herbicide-resistance management may be implemented.

Definition

Resistance isdefine as ‘‘the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis.’’

Secondly, *resistance* is defined as the evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide application and complete its life cycle when the herbicide is used at its normal rate in an agricultural situation (Heap and LeBaron, 2001).

Role of Herbicide in Agriculture

Agricultural production Indonesia, especially oil palm plantation plays an important role in economic growth. Weed control is an important and expensive component of plantation crop management (Khairudin and Teoh, 1990). It is estimated that the cost incurred to control weed may account for 17 to 27 percent total upkeep cost in immature or mature oil palm (Azahari*et al*, 2004). There are several weed control methods may be implemented in oil palm field however herbicides are considered as the most popular tool mainly on modern oil palm management. Among herbicides, paraquat, glyphosate, and glufosinate ammonium are the most commonly used herbicides in oil palm plantation (Chung and Sharma, 1999; Madeley, 2003). In Malaysia, the use of herbicides in 2004 contributed to 67.49% of the total pesticides used, and herbicide use was predicted at 15.6 million litres in oil palm in 2005 (Malaysia Agricultural Directory and Index, 2003/2004).According to Atkin and Leisinger (2000), growers prefer an effective herbicide with acceptable cost.

Herbicide usage for weed control in oil palm plantation has been a common practice since nearly five decades ago. Herbicide usage is hardly separated from oil palm plantation business. This form of weed control method often more reliable and least expensive method compared to other methods available. The efficacy and cost effectiveness of herbicides for weed control has led to heavy reliance on herbicides in agricultural production in developed countries (Heap and LeBaron, 2001). In Indonesia, National Pesticide Society (2011) stated that 82% of total herbicide is used in plantation crops and 57.5% of this is used in oil palm plantation. In other words, more than 50% herbicide is used in oil palm plantation area. Ninety two percent of the total herbicides used in Indonesia consisted of glyphosate and paraquat(National Pesticide Society, 2011). Herbicides, mainly glyphosate and paraquat, are applied 3 to 4 rounds per year in oil palm field continually for 20 to 25 years of oil palm age and often the sole herbicide used to control weeds. This reliance on one mode of action (MOA) for a long period of time inevitably imposed intense selection pressure on weed populations. Recently, many weed control failures have been reported in oil palm fields. Glyphosate- and paraquat-resistant weeds are becoming a major problem in oil palm.

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The herbicides make major contributions to oil palm production by easily removing weeds and substituting for destructive soil cultivation. However, persistent herbicide selection of huge weed numbers across vast areas can result in the rapid evolution of herbicide resistance. In the last four years, planters in North Sumatra,

Indonesia has often reported that glyphosate and paraquat were no longer control goosegrass satisfactorily. Failure to control weed with herbicides such glyphosate and paraquat make weed control methods available become limited.

Herbicide Resistance Development

Resistant weeds have been evolving in crop cultivars worldwide from selection pressure placed on them from repeated use of herbicides. A plant does not evolve resistance because herbicides cause a genetic change in the plant that makes it resistant. Rather, a few plants with natural resistance to the herbicide survive an application of the herbicide, and as those plants reproduce and each generation is exposed to the herbicide, the number of resistant plants in the population increases until they dominate the population of susceptible plants.

Charles Darwin in his book (1859) *On the Origin of Species by Means of Natural Selection*stated that species survived through a process called "natural selection," where species that successfully adapted to meet the changing requirements of their natural habitat thrived, while those that failed to evolve and reproduce died off.Weed populations change, sometimes rapidly, in response to pressures exerted on them by human endeavors. When plants were first domesticated for agricultural purposes, native plant populations began changing as mankind began to select for certain plants that were more desirable as food sources and weeds began to interfere with production of the desired species. Clearly some of the most easily recognizable selection pressures today come from management practices utilized by modern agriculture, such as herbicide use. Herbicides are not the only selection pressure exerted by modern agriculture. Tillage, fertilization practices, crop selection and rotation, and irrigation practices, among other factors, can result in weed community changes (Ball and Miller 1990). However, herbicide use probably results in more rapid changes than that caused by some of the other practices, and for the most part herbicide resistance is more easily observable. The effect of weed resistance is often dramatically observed in the field.

In most parts of the world, herbicides are the dominant technology used for the control of weeds that infest crops. Consequently, in situations of intense herbicide usage, there have been many examples of the evolution of weed populations resistant to herbicides (Powles and Yu 2010). From an evolutionary perspective, many factors influence the dynamics of herbicide resistance evolution under herbicide selection (Jasieniuk*et al*. 1996). One crucial factor in herbicide resistance evolution is the intensity of herbicide selection, of which a major determinant is the herbicide use rate. Herbicides, when used at the correct plant growth stage and at the registered label rate, cause very high mortality. However there may be individual plant withstand the herbicide application which keep growing and reproduce seeds for the next generation. Plants grow from seeds of survivors will increase the number of plants resistant to the herbicide. This selection occurs continually as long as the same herbicide is repeatedly used and finally resistant weed population become dominant.

Sublethal dose herbicides is another factor to increase the development of resistance. Many stresses increase the rate of mutations, and low dosesofherbicidescanbestressfulbutnotlethal,thusincreasing the rate of mutation

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(Gressel and Levy, 2009). In some cases, resistance appeared in a clearly high mutation background, e.g. triazine resistance first appearedinsomespeciesinabackgroundofmosaicsontheleaves. In such cases, sexual crosses will segregate the other mutations from herbicide resistance if there is continual selection pressure by the herbicide. This provides another reason why it is valuable torotateherbicidestoprecludethisfromhappening.Lowratesof herbicide also canfacilitate arapid creepof resistance by increasing the frequencies of mutations, including mutations for resistance (Gressel and Levy, 2009). Manalil*et al* (2011) found that low level dose of diclofopexposed to *L. rigidum*enhance herbicide resistance evolution. Similarly, Busi*et al* (2012) reported that persistent pyroxasulfone use at low dose has the potential to rapidly lead to herbicide resistance evolution in *L. rigidum*populations.

Identifying the main factors influencing the evolution of resistant weed populations is crucial for understanding, predicting and managing herbicide resistance. It has been observed that selection at low (sublethal) glyphosate doses in cross-pollinated, genetically variable *Lolium* can lead to glyphosate resistance evolution. Resistance in weeds due to selection at sublethal dose are of special significance because of the importance of glyphosate in world food production and the recent evolution of several glyphosate-resistant weed biotypes (Powles, 2008). Herbicides should be used at the recommended rate to achieve high weed mortality and therefore minimize the possibility of accumulation of minor gene traits (creeping resistance) that may endow a level of resistance over a few generations. The rapid evolution of glyphosate and diclofop-methyl resistance (Neve and Powles, 2005) due to the recurrent use of low (sublethal) herbicide doses warrants future research on other herbicide modes of action. Substantial precautions need to be taken by the industry to ensure that herbicides are used at the registered recommended rates. Otherwise, what we have (glyphosate and paraquat for example) at the present may no longer be effective on our plantations. Therefore the sustainability and longevity of herbicide molecules in oil palm plantation should be taken in a serious precaution.

The evolution of herbicide-resistant weeds in oil palm has been a major production issue during the last decade. Therefore, herbicide-resistant weed populations have been a problem not only in developed countries but also in developing countries such as in Indonesia where some tropical crops, for example oil palm, resistance continually increase to evolve. The reason behind this occurrence is that weed control tactics mostly rely on herbicide usage. The focus for weed management, particularly in oil palm, has been on herbicides, often to the exclusion of all other available tactics. While the use of herbicides has been historically effective and efficient, resultant changes in the agro-ecosystem, specifically in the weed community, have become an issue. Further, legitimate concerns about the impact of herbicide tactics on the environment have been expressed. Thus, it is important to determine how herbicides impact oil palm production systems and the weed communities. Tabel 1. Factors influencing herbicide resistance evolution in weed populations

Genetic
1. Frequency of resistance genes
2. Number of resistance genes
3. Dominance of resistance genes
4. Fitness cost of resistance genes

Biology of weed species
1. Cross-pollination versus self-pollination 2. Seed production capacity 3. Seed longevity in soil seedbank 4. Seed/pollen movement capacity
Herbicide
1. Chemical structure 2. Site of action 3. Residual activity
Operational
1. Herbicide dose 2. Skills of the operator (treatment machinery, timing, environmental conditions, etc.) 3. Agro-ecosystem factors (non-herbicide weed control practices, crop rotation, agronomy, etc.)

Herbicide resistance is an evolutionary process, and its dynamics and impact are dependent upon the factors summarized in Table 1 (Powles and Yu, 2010).

Resistant weeds have been evolving worldwide from selection pressure caused by the repeated use of herbicides with the same mode of action (MOA) in conventional crop cultivars. The herbicide selects for plants with some level of natural genetic resistance to that MOA.

Current Herbicide-Resistance Status

Herbicide resistance in weeds is a global problem. The first herbicide resistance case was reported in *Senecioviulgaris* which was resistant to triazineherbicides by Ryan in 1970. The weed was no longer be able controlled by triazine after being used for years in the the population. Since then herbicide resistance cases are increasingly reported from around the globe.

There are currently 471 unique cases of herbicide resistant weeds globally, with 250 species (145 dicots and 105 monocots). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 160 different herbicides. Herbicide resistant weeds have been reported in 86 crops in 66 countries (Heap, 2016).

Glyphosate-resistant case was first reported in Victoria, Australia in 1996. Today glyphosate resistance has been found in 35 weed species which consist of 15 grasses and 20 broadleves. On the other hand, paraquat resistance has been found in 31 weed species (8 grasses and 23 broadleaves). The first paraquat-resistant weed was reported in *Hordeumglaucum* in 1984 in Australia whereas the first paraquat-resistant *E.indica* was reported in 1990 in Malaysia.

Herbicide-resistant *E.indica* has been occurred in 11 countries (Argentina, Australia, Bolivia, Brazil, China, Colombia, Costa Rica, Indonesia, Japan, Malaysia, and USA) which resistant to one or more of these 16 herbicides (clethodim, cyclahop-butyl, fluazifop-P-butyl, haloxyfop-methyl, glyphosate, fenoxaprop-P-ethyl, sethoxydim,

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paraquat, imazapyr, propaquizafop, glufosinate ammonium, butroxydim, trifluralin, pendimethalin, prodiamine, and metribuzin).

We have documented that six populations of *E. indica* collected from six oil palm fields in North Sumatra confirmed to have developed resistance to glyphosate and/or paraquat. Moreover, resistance test for 56 populations of *E. indica* collected from one estate with the size around 4000 hectares (one estate consists of nine “afdelings”) was found that 95% of the populations have developed resistance to glyphosate and paraquat (Figure1 and 2).

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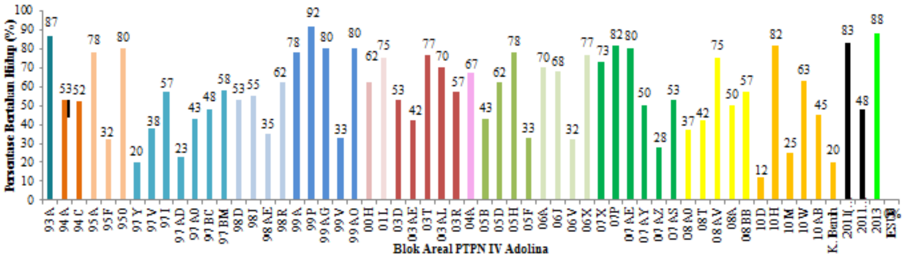
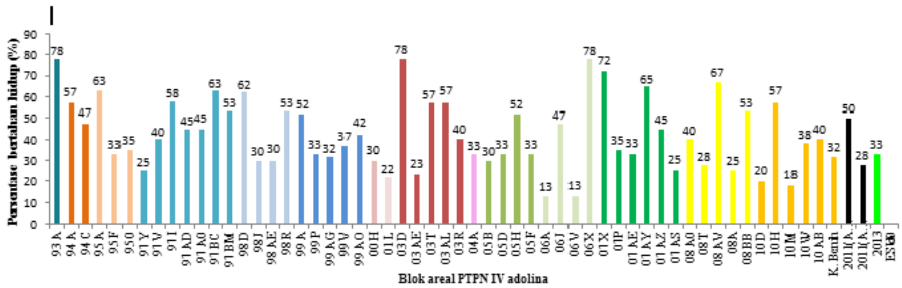


Gambar 1. Persentase gulma bertahan hidup rumput belulang 3 MSA glifosat (480 g b.a/ha) pada populasi 58 blok kebun Adolina dan populasi sensitif

Keterangan warna histogram(tahun tanam)							
	1993		1999		2005		2011
	1994		2000		2006		2013
	1995		2001		2007		
	1997		2003		2008		
	1998		2004		2010		

Chart Area



Gambar 2. Persentase gulma bertahan hidup rumput belulang 3 MSA parakuat (300 g b.a/ha) pada populasi 58 blok kebun Adolina dan populasi sensitif

Keterangan warna histogram(tahun tanam):							
	1993		1999		2005		2011
	1994		2000		2006		2013
	1995		2001		2007		
	1997		2003		2008		
	1998		2004		2010		

Chart Area

Herbicide Resistance

Management

Planters are asked to make an action for weed resistance management. The call to action for oil palm planters, involves four objectives. First, planters must educate themselves with an understanding of the causes of herbicide resistance and the types of strategic approaches that will help avoid the increase in resistance in the future. Second, choosing valid information sources is critical to success, making sure the information relied upon for decision making is based on sound science and experience and is appropriate for local conditions. Third, attention to what is happening in fields, particularly after herbicide applications, is critical. Herbicide resistance does not happen overnight. Identifying the first occurrence in a field is critical and the only way to do that is to monitor for treatment effectiveness and properly address any weeds that escape treatment. Fourth, a long-term view of operations is important to the success of herbicide resistance management. It is clear that field-by-field weed management plans that include a diversity of approaches are necessary over years to maintain the susceptibility of weed populations to herbicides.

Herbicide-resistant weed management practices most often recommended by weed scientists include (1) using different herbicide MOAs in annual rotation, tank mixtures, and sequential applications; (2) expanding the use of cultural control measures, such as planting leguminous cover crops (3) using only labeled herbicide rates (do not reduce) at labeled application timings; (4) preventing seed movement; (5) scouting fields; and (6) controlling weed escapes.

In other words, to avoid or delay the development of resistant weeds, a diverse, integrated program of weed management practices is required to minimize reliance on herbicides with the same MOA. Weed management diversity must include herbicidal and nonherbicidal weed control strategies. One nonherbicidal strategy is prevention of physical movement of weed seeds or propagules to uninfested areas by cleaning equipment, preventing movement of plant reproductive structures, and by the timely scouting of fields and controlling of weeds that escape herbicidal control. Other methods are the use ofcultural control tactics: manual weeding, legume cover crops, mulches. These methods can be used to prevent or delay herbicide resistant population.

An understanding of grower perception of weed management and herbicide resistance informs weed scientists as to where and how best to focus education and training programs. Besides, planters, university and industry scientists, and regulators could establish aHerbicide Resistance Action Committee as a task force for herbicide-resistance stewardship in the region.The committee may also provide advice to regulators to put the herbicide mode of action code on label to ease growers implementing diversity of herbicide program.

The single, most important lesson learned in managing weed resistance to herbicides is that the maintenance of a diversity of weed-management tactics is critical for sustaining the use of herbicide options. Overreliance on a single herbicide or a group of herbicides within the same MOA group without concurrent use of other weed-management options has encouraged the evolution of weed populations resistant to these intensively used herbicides.

An integrated weed management (IWM) or integrated pest management program for weeds in oil palm field is developed by combining strategies from several broad categories of weed control tactics: preventive, cultural, mechanical, biological, and chemical control (herbicides). Planting legume cover crops on oil palm field are a way of not only minimizing weed populations but also prevent soil erosion (Moore et al. 1994). A legume cover crop is usually grown before crop seedling transplanted so that vegetative cover remains on the field for as long as possible during the year (Melander et al. 2005). Several advantages accrue from cover crops. They help growers meet conservation-tillage requirements for yearround vegetation cover; aid in soil erosion prevention; improve soil structure (increase organic matter content); improve soil fertility (fix nitrogen); and possibly suppress weed emergence and growth (Akemo et al. 2000; Krutz et al. 2009; Melander et al. 2005; Norsworthy et al. 2011). Suppression of weeds by legume cover crops depends partly on biomass production of the cover crop. *Mucunabracteata* grows rapidly and produce high biomass production compare to other conventional legume cover crops.

The Impact of Resistance

Herbicide-Resistant weeds result in some impacts such as reduced yield, increased production costs, and loss of control. Failure to control weeds around the oil palm tree will result in more competition on water and nutrients between weed and oil palm.

Most of oil palm plantations in Indonesia and Malaysia use herbicides as weed control tool. Failure to control weeds with herbicides due to resistance increase production costs because plantation managers often increase herbicide dose although it does not control the weed satisfactorily or they control weeds using man power which is usually far more expensive compared to herbicide use when it was not resistance.

Planters, especially those with lack ofunderstanding on herbicide resistance usually notice herbicide resistance by the time herbicide resistance becomes apparent when it is already too late. In that stage cost-effective weed management tool can no longer do the job it once did. It is not rare that planters do complaining to herbicide supplier when herbicides they have been using for a long time no longer effectively control weed.

It is therefore all oil palm fields are under threat, as long as no diversity of weed control – so it is an urgent need to use the full range of weed control products and other management techniques to slow the development of resistance and reduce its impact.

Conclusion

Herbicide resistance has become a global phenomenon. Discovery of resistance to glyphosatehas proven to be one of the most important findings in agriculture including in oil palm fields. If glyphosateresistant weeds are not controlled by some other means, the resistant biotype rapidly predominates, reproduces and becomes a solid infestation that can no longer be controlled by the herbicide. If only glyphosate herbicides are available to control weeds in oil palm, the planter may no longer be able to produce the palm oil economically.

Planters need to implement “diversity” on weed control program such as mixing or sequencing different mode of action herbicides as part of their weed management in order to keep a herbicide effectively to control weeds. Herbicides with the same mode of action should not be applied repeatedly for a long period of time.

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