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Glyphosate Use in Asia and Implications of Possible Restrictions on its Use

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This study examined the farm level implications of restrictions on glyphosate use. These are likely to be higher weed control costs, poorer levels of weed control, increased incidence of pests, lower yields and loss of benefits associated with no tillage and the adoption of GM HT crops. There is likely to be more use of alternative herbicides and additional use of manual, mechanical, and cultural weed control methods. These changes are expected to increase the annual cost of weed control across the seven countries by between $22/ha and $30/ha. In relation to the environmental impact associated with herbicide use, it is likely to result in a small decrease in the total amount of herbicide active ingredient used across the seven countries (-1% to -11%) although in terms of the associated environmental impact, as measured by the EIQ indicator, the average EIQ load/ha would increase by between 0.4% and 11.6%, highlighting a net poorer environmental outcome.

Key words: glyphosate, weed control, hand weeding, environmental impact quotient, active ingredient, costs, yield.

Introduction

The International Agency for Research on Cancer (IARC) re-evaluated the potential carcinogenic risk to humans of several pesticides, including glyphosate in 2015 (IARC, 2015). IARC concluded that glyphosate belongs in a 2A category as probably carcinogenic to humans.

While numerous regulatory authorities around the world (e.g., Australian Pesticides and Veterinary Medicine Authority [APVMA], 2017; Canadian Pest Management Regulatory Agency [CPMRA], 2017; European Food Safety Authority, 2015; Temple, 2016; US Environmental Protection Agency [EPA], 2016) have re-examined the safety evidence relating to glyphosate since 2015 and subsequently re-affirmed that glyphosate does not cause cancer, a number of governments are still considering establishing restrictions or limits on the use of glyphosate in agriculture. Some of these countries are in Asia (e.g., Thailand and Indonesia).

To contribute to the debate about the possible implications of restrictions on glyphosate use, this article examined the current use of glyphosate, reasons for its use and how farmers might change weed control practices if they could no longer use glyphosate in seven countries of the region—Australia, China, India, Indonesia, Philippines, Thailand, and Vietnam. These countries were selected for the study because they include the largest agricultural users of glyphosate in the region, countries considering possible restrictions the use of glyphosate and countries using genetically modified herbicide tolerant (to glyphosate) crops (source: Kleffmann glyphosate usage data, 2010-2015).

Materials and Methods

The analysis was undertaken in two distinct phases and based on two different types of data source. Firstly, detailed farm-level usage data for glyphosate and other herbicides, including aggregated (to crop and national level) data was identified. A search of the literature on herbicide use shows that national level herbicide usage survey data is limited; there are no published, detailed, annual herbicide usage surveys conducted by national authorities in any of the main agricultural economies in Asia and therefore the author has drawn on herbicide usage data collected annually by private market research companies. This data is collected from a combination of in-country farm surveys of usage and professional (extension advisors, industry representatives) estimates based on herbicide sales and knowledge of farm weed control practices. It is typically compiled annually and made available to customers on a subscription basis. The author has been able to access this information via the subscriptions of the main sponsor of this research, Monsanto Company. As a source of data, it represents a consistent, annually updated, detailed source that allows for comparisons to be made between crops and between countries. Given it is regularly accessed on subscription by leading agro-chemical companies, the author considers it reasonably representative of actual usage of herbicides by crop in each country.

Based on this dataset (sources: Kleffmann and Kynetec), total agricultural glyphosate use in active ingredient terms was identified for all Asian countries for which data is collected. The largest ten users of glyphosate (in descending order of usage) are China, Australia, Thailand, India, Philippines, Indonesia, Japan, Vietnam, South Korea, and Malaysia (source: Kleffmann). The leading six glyphosate user countries plus Vietnam were selected for further analysis (Vietnam rather than Japan was selected for more detailed analysis because GM HT (tolerant to glyphosate) corn was in its second year of commercial usage at the time the research started (late 2016).

For each of the seven countries, detailed analysis of herbicide use (by active ingredient) and by crop/agricultural usage was made and summaries of this analysis are presented in the results section below. Through this, the main uses and crops where glyphosate is used were identified. This provided the baseline for the second phase of the research, to undertake in-country analysis of the implications if glyphosate use was no longer permitted.

To better understand and quantify potential impacts of restrictions on glyphosate use, research, in the form of semi-structured interviews, was undertaken with representatives of organisations in each country who have good knowledge of production practices and weed control in the main crop/user sectors where glyphosate is currently used. Across the seven countries 975 interviews were undertaken (Australia 380, China 81, India 160, Indonesia 72, Philippines 62, Thailand 161, and Vietnam 59). These interviews were conducted with extension advisors, plantation owners/weed control advisors, industry advisors, and farmers. Where farmers were interviewed in the countries where GM HT crops are grown (Australia, Philippines, and Vietnam), these included farmers growing these crops. Additional information about the questions asked is presented in Appendix 3.[1]

The process for identifying and selecting the sample of interviewees was as follows:

- Crop focus was based on the glyphosate usage data (sources: Kleffmann/Gfk).
- The main regions in which these highest glyphosate using crops were identified, with interview numbers based on the regional distribution of these crops.
- Where extension advisors were interviewed, these were identified from publicly available (internet) sources (e.g., of local/national extension services and universities) and/or knowledge of industry (crop/use) advisors;.
- Where farmers were interviewed, these were identified from a combination of publicly available (telephone) directories and knowledge of seed/glyphosate sales from industry (sponsor) and extension services.
- Interviewees were selected for interview on a random basis from the above two 'populations' until each crop and region-specific target interview numbers had been fulfilled.

An example is presented below for the Philippines (Table 1), with additional information for the other countries presented in Appendix 1.

Assessment of the environmental impact associated with any change in weed control practices, if restrictions were placed on the use of glyphosate, requires comparisons of the respective weed control measures used on the 'with glyphosate' versus the 'without glyphosate alternative' form of production. The 'with glyphosate' baseline relating to herbicide use was identified from Kleffmann/Kynetec data for each of the main crops in which glyphosate is used, to the active ingredient level. The 'without' glyphosate alternatives were identified from the in-country interviews with extension advisors, industry experts and farmers.

In addition, the environmental impact quotient (EIQ; Kovach, Petzoldt, Degni, & Tette, 1992; updated annually) of each herbicide active ingredient used under the 'with glyphosate' and 'without glyphosate' were calculated and compared so as to provide an assessment of the impact on the environment according to both

1. *The number of interviews undertaken in each country was small and not fully representative of all sectors of agriculture or necessarily representative of regional distribution of crops. This is a weakness of the research, which was caused by budget constraints. Nevertheless, by identifying the main crops in which glyphosate is used in each country and estimated usage levels via Kleffmann/Kynetec data, it was possible to concentrate the interviews amongst experts and farmers in the main glyphosate using crop sectors. Therefore, the author considers the findings of this second stage of the research to have produced findings that are reasonably consistent across countries and are consistent with findings of similar work in other countries (e.g., Abeywickrama, Sandika, Sooriyarachchi, & Vidanapathirana, 2017, relating to Sri Lanka; Gouse, 2014, relating to South Africa; Fairclough, Mal, & Kersting, 2017, relating to Germany; Bouchet & Cocard, 2013, relating to France; and Wynn, Cook, & Clarke, 2014, relating to the UK).*

Table 1. Philippines: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Corn	44	20 (32%)	7 of which used GM HT corn (GM HT corn accounts for about 30% of the total corn planted area in 2017)
Non-crop use	15	6 (10%)	Included information from 2 extension advisors
Rubber	7	5 (8%)	Plantation crop
Bananas	7	10 (16%)	Plantation crop
Tropical fruit	7	5 (8%)	Plantation crop
Rice	4	6 (10%)	
Sugar cane	4	2 (4%)	Plantation crop
Others	12	8 (13%)	

Notes:

1. *Target number of interviews 60 (limit based on budget available)*
2. *Interviews were 60 with farmers and 2 with advisors. Farmers in relation to crops of oil palm, rubber, sugar cane and tropical fruit includes plantation (in-house/employed) agronomists*
3. *Others: included cassava, citrus fruit and coconut*
4. *Tropical fruit (main crop mango)*
5. *Interviews conducted July-September 2016*

changes in the amount of herbicide applied and their toxicity. As acknowledged in other literature (e.g., Brookes, Taheripour, & Tyner, 2017), the EIQ indicator is a better indicator of environmental impact than looking at changes in amount of active ingredient use alone. However, it is only a hazard indicator and has important weaknesses (e.g., Kniss & Coburn, 2015; Peterson & Schleier, 2014). It does not assess risk or probability of exposure to pesticides and relies on qualitative assumptions for the scaling and weighting of (quantitative) risk information that can result, for example, in a low risk rating for one factor (e.g., impact on farm workers) may cancel out a high-risk rating factor for another factor (e.g., impact on ecology).

Despite these weaknesses, the EIQ indicator was used in this article because it summarizes significant amounts of information on herbicide impact into a single value that, with data on usage rates (amount of active ingredient used per hectare from Kleffmann/Kynetec data) can be readily employed to make comparisons between the two production systems across crops, regions, and countries. It therefore provides an assessment (albeit fairly crude) of the environmental impact associated with a move from a 'with glyphosate' to a 'without glyphosate' production system that would not otherwise be available, if the criteria for assessing environmental impact required all of the EIQs weaknesses to be adequately addressed—such a full environmental impact assessment would require a complex evaluation of risk exposure to pesticides at a site-specific level and would require the collection of (site-specific) data (e.g., on ground water levels, soil structure) and/or the application of standard scenario models for exposure in a number of locations. Such detailed information across a range of crops, regions and countries is simply not available.

Results

Context of Glyphosate Use in Agriculture

Glyphosate is widely used in agriculture for weed control across a range of crops and is a key part of the production system that uses genetically modified herbicide tolerant (GM HT) crop technology. Glyphosate is used for weed control in three main circumstances:

- In land preparation before planting. This may be part of ground clearance (e.g., for plantation crops) or to clear weeds and old crop material before planting of seasonal and field crops (e.g., corn, rice);
- Between crop rows and surrounding field edges and bunds during crop growth. This occurs mostly in plantation crops, but also by some farmers growing field crops;
- 'Over the top' weed control in GM HT (tolerant to glyphosate) crops—notably cotton grown in Australia, corn in the Philippines and Vietnam, and canola grown in Australia.

Total annual global use of glyphosate is in the range of 450 to 500 million kilograms of active ingredient (source: Kleffmann), of which GM HT crops account

Table 2. Proportion of main crops using herbicides (and glyphosate) as the main form of weed control by country (%).

	Australia	China	India	Indonesia	Philippines	Thailand	Vietnam
Bananas	N/r	100 (47)	N/r	N/r	25 (10)	N/r	N/r
Rice	N/r	90 (4)	21 (4)	75 (37)	60 (3)	55 (1)	95 (3)
Corn	100 (90)	83 (5)	20 (2)	20 (7)	31 (28)	100 (3)	85 (7)
Other cereals	100 (45)	N/r	N/r	N/r	N/r	N/r	N/r
Rubber	N/r	N/r	N/r	70 (37)	56 (54)	50 (34)	99 (85)
Sugarcane	90 (67)	N/r	30 (3)	50 (13)	25 (5)	100 (10)	90 (21)
Oil palm	N/r	N/r	N/r	67 (50)	N/r	67 (49)	N/r
Fruit	N/r	90 (17-64)	100 (41)	25 (19)	10 (8)	75-100 (10-40)	50-64 (20-25)
Vegetables	N/r	50 (9)	11 (5)	N/r	N/r	N/r	N/r
Coffee	N/r	N/r	N/r	N/r	N/r	N/r	63 (46)
Tea	N/r	75 (26)	90 (72)	N/r	N/r	N/r	75 (30)
Cotton	100 (100)	67 (11)	35 (30)	N/r	N/r	N/r	N/r
Canola/rapeseed	100 (30)	80 (13)	N/r	N/r	N/r	N/r	N/r
Vines	90 (40)	N/r	N/r	N/r	N/r	N/r	N/r
Pasture	70 (12)	N/r	N/r	N/r	N/r	N/r	N/r

Sources: Kleffmann and Kynetec

Notes:

- *% of crop using glyphosate values in brackets*
- *2012 data for Indonesia, Philippines and Thailand, 2014 data for Australia, China and Vietnam and 2015 data for India*
- *N/r = not an important user of glyphosate*
- *Fruit: China relates to citrus, India is pome fruit, Indonesia and Philippines are tropical fruit based on mango, Thailand is tropical fruit based on durian, mango and rambutan and Vietnam is tropical fruit based on lychees and mango*
- *Corn in Philippines and Vietnam includes GM HT crops (28% and 5% respectively of the total crops in 2016)*
- *Canola and cotton in Australia includes some GM HT crops (20% and 100% respectively of each crop in 2016)*

for about two-thirds of this total global usage.[2] The seven countries in Asia—the focus of this article—use about 82 million kg of glyphosate active ingredient associated with agricultural uses per year (16%-18% of global use).

Husbandry practices to control weeds in agriculture are typically a combination of herbicide use, land/soil preparation, and mechanical or hand/manual weeding. The importance of herbicides for weed control varies by crop and country—Table 2 shows the relative importance of herbicide and glyphosate use for weed control in the main crops where glyphosate is used in the seven countries. Herbicides dominate weed control practices in all crops in Australia, China, Thailand, and Vietnam but are less prominent in India, Indonesia, and the Philippines. In these latter countries, herbicide use tends to be more widely used in commercial crops and less used in subsistence crops (e.g., corn in the Philippines, where herbicides are used on about 30% of the total crop and only about one-third of the crop is commercial).

Where herbicides are used for weed control, glyphosate is one of the most important and widely used active ingredient accounting for between 13% and 73% of total herbicide active ingredient use across the seven countries and between 7% and 38% of the total area sprayed with herbicides (Figures 1 and 2).

The main crops/uses for glyphosate show both some similarities and differences between countries (Tables 2 and 3). A summary of the key features of glyphosate use by crop/country is presented below, with additional information by crop/country presented in Appendix 2.

Australia. More than half (53%) of total glyphosate use (in terms of active ingredient use) is for non-crop-specific use and primarily in summer fallow. The next most

2. *This share of total glyphosate use accounted for by GM HT crops tolerant to glyphosate assumes all GM HT crops are tolerant to glyphosate and the farmers that use this technology use glyphosate for weed control. However, some GM HT crops include tolerance to other herbicides and/or are only tolerant to other herbicides (e.g., glufosinate). Therefore, some farmers may use herbicides like glufosinate with their GM HT crops for weed control and the extent to which this occurs may overstate the actual share of total glyphosate use accounted for by GM HT crops. The author is not aware of any estimates of usage of herbicides other than glyphosate for 'over the top' spraying of GM HT crops.*

Table 3. Average glyphosate use (kg/base ha active ingredient) by crop.

	Australia	China	India	Indonesia	Philippines	Thailand	Vietnam
Bananas	N/r	2.4 (2)	1.8 (2)	3.92 (2)	2.82 (2)	N/r	2.88 (2)
Rice	0.41	2.27	0.55	0.11	0.71	0.43	0.95
Corn	0.7	1.16	1.24	1.41 (1.2)	1.41 (1.5)	2.16	1.44
Other cereals	0.63	1.23	1.0	N/r	N/r	N/r	N/r
Rubber	N/r	1.64	N/r	1.08	0.95	2.38	2.7 (2)
Sugarcane	1.38 (2)	1.79	1.19	0.17	1.92 (2)	4.8 (2)	2.88 (2)
Oil palm	N/r	N/r	N/r	3.04 (2)	1.92 (2)	6.93 (3)	N/r
Fruit	1.38 (2)	2.88 (2)	1.36 (2)	2.82 (2)	1.86 (2)	3.84 (2)	2.88 (2)
Vegetables	1.44	2.46 (2)	1.2 (2)	3.18 (2)	1.8 (2)	3.36 (2)	2.42 (2)
Coffee	N/r	N/r	N/r	0.6	0.95	N/r	2.78 (2)
Tea	N/r	3.84 (2)	1.8	3.28 (2)	N/r	N/r	2.7 (2)
Cotton	2.76 (3)	1.45	1.0	N/r	N/r	N/r	1.07
Canola/rapeseed	0.67	1.12	N/r	N/r	N/r	N/r	N/r
Vines	0.71	1.99	1.14	N/r	N/r	N/r	2.88 (2)
Pasture	0.6	N/r	N/r	N/r	N/r	N/r	N/r

Sources: derived from Kleffmann and Kynetec

Notes:

- *Bracketed figures are average number of applications making up this total—assumed 1 unless stated*
- *Australia cotton: all GM HT (tolerant to glyphosate), canola average one treatment although GM HT 1.5 average*
- *N/r = not relevant crop/do not use significant amounts of glyphosate*
- *Philippines corn mostly GM HT (tolerant to glyphosate)*

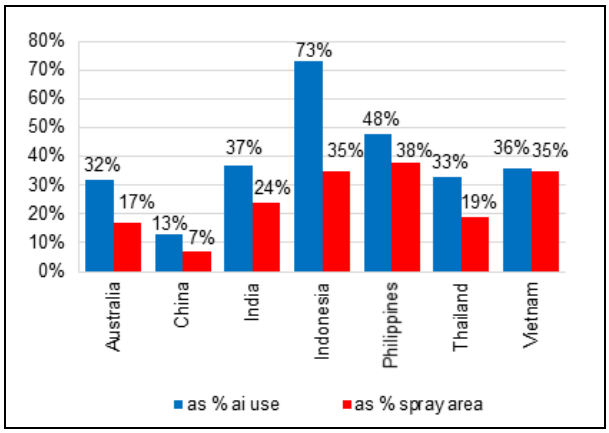

Figure 1. Glyphosate use as a percentage of total herbicide use by country.

Sources: Kleffmann and Kynetec

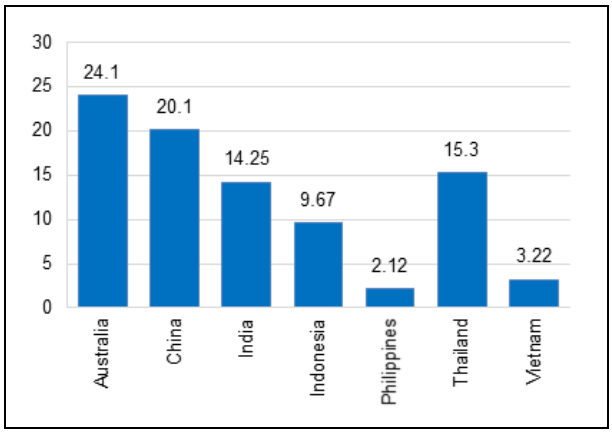

Figure 2. Annual glyphosate use by country (million kg active ingredient).

Sources: Kleffmann and Kynetec

important user crops in terms of total glyphosate active ingredient use are cereals (22%), forage crops (14%), cotton (5%), and canola (3%). In the latter two crops GM HT (tolerant to glyphosate) crop technology is used (used on all of the cotton crop and about 20% of the canola crop). Overall, glyphosate accounts for about a third of total herbicide active ingredient used, in a country where herbicides are the primary form of weed control in agriculture. The literature reviewed (e.g., Cameron & Storrie, 2014) shows that glyphosate is important for weed control in the pre-planting and fallow phases. This is essentially a 'burndown' phase where weeds are cleared from land before seeds are sown or crops planted (typically one treatment of glyphosate is used). This also includes where some farms plow their land, clear vegetation/weeds and/or practice no or reduced forms of tillage agriculture.[3] Similarly, glyphosate has a long history of use in summer fallow

for the control of a broad range of weeds. In fruit, vegetable, sugarcane, and grape (wine production) crops, glyphosate is used for between crop weed control, with 3-4 treatments per year being common practice.

China. Glyphosate is used across a wide range of crops, with the largest use recorded in fruit, rice, tea, vegetables, and corn accounting for 34%, 12%, 9%, 9%, and 9%, respectively, of total glyphosate use. Glyphosate accounts for 13% of total herbicide active ingredient used and relative to other countries in Asia, China is the highest user of glyphosate (in terms of active ingredient per ha) when used in rice, cereals, tea, and canola. Weed control in all crops commonly comprises a mix of mechanical weeding, hand weeding, and application of herbicides. In field crops, glyphosate is only used for land preparation before sowing of the crop (a single application), while in perennial crops and vegetables it is used for weed control in land preparation and between trees/bushes (2-3 applications per growing season).

India. Hand and mechanical weeding are the primary forms of weed control in all crops/uses. Herbicides, though widely used, are commonly limited to a single application. Glyphosate accounts for 37% of total herbicide active ingredient used and relative to other countries in Asia, average usage of herbicides (active ingredient per ha) in India is lowest for bananas, fruit, vegetables, tea, and cotton. Three-quarters of glyphosate use is accounted for by cereals, cotton, and fruit/vegetables (each accounting for about a quarter of total use).

Indonesia. Herbicides are widely used on all crops for weed control, though usually supplemented by the use of mechanical and hand weeding (notably in tropical fruit and sugarcane where these are the only forms of weed control used on three-quarters of the fruit crop and half of the sugarcane crop). Glyphosate accounts for 73% of total herbicide active ingredient used with the main user sector, accounting for nearly two-thirds of total glyphosate use, being oil palm (glyphosate is used both in land preparation and between crops during the growing season, with up to three applications per year). The next most significant user sectors are rice, corn, non-crop use, and rubber which accounted for 11%, 7%, 6%, and 4%, respectively, of total glyphosate use. Usage in the field crops of corn and rice is more limited and typically a single application as part of land preparation, while in rubber and non-crop use, glyphosate is commonly applied 2-3 times per year (e.g., for weed control in-between plants in rubber).

Philippines. Similar to Indonesia, herbicides are widely used for weed control, though commonly as a secondary/supplementary form of weed control to mechanical and hand weeding. Where herbicides are used, glyphosate accounts for 48% of total active ingredient used. The main glyphosate user crop is corn (44% of total use), mainly because a quarter of the crop (655,000 ha) uses GM HT (tolerance to glyphosate) technology. In this crop, glyphosate is typically applied twice during the growing season and is the primary form of weed control. In conventional corn (and rice), glyphosate is sometimes used in land preparation (one application). The next most important user sectors are non-crop (e.g., land clearance, forestry, and roadside), rubber, top fruit, and sugarcane which account for 15%, 7%, 7%, and 4%, respectively, of total glyphosate use.

Thailand. While all three forms of weed control (mechanical, manual, and herbicides) are commonly used in agriculture, herbicides are the primary form of weed control in most crops. Glyphosate accounts for 33% of total herbicide active ingredient used by farmers, with the two main glyphosate user sectors being rubber and other plantation crops (e.g., bananas, tamarind). These two crop categories each account for about 35% of total herbicide use. As in the other countries where plantation crops are widely grown (e.g., Philippines, Vietnam, Indonesia), glyphosate is used both in land preparation and for in-crop weed control, with 2-3 applications (of glyphosate) commonly made each year. The next most important glyphosate-user sectors are oil palm and cassava (11% and 4%, respectively, of total glyphosate use), where glyphosate is typically used in both land preparation and for in-crop weed control.

Vietnam. Similar to Indonesia and Philippines, herbicides are widely used for weed control, though commonly as a secondary/supplementary form of weed control to mechanical and hand weeding. In relation to total herbicide use, glyphosate accounts for 36% of total active ingredient use. Rubber is the largest glyphosate user sector, accounting for 57% of total usage. The next most important user crops are coffee, rice, and sugarcane (12%, 6%, and 5%, respectively, of total glyphosate use). In plantation crops, glyphosate is

3. *It should be noted that more than three-quarters of grain farmers practice reduced or no tillage production methods (Llewellyn & D'Emden, 2010).*

commonly applied 2-3 times per year for land preparation and in-between crop weed control.

Implications of Restrictions on Glyphosate Use in Agriculture

A significant area where glyphosate is currently used for weed control is in the pre-planting phase. This is essentially a 'burndown' phase where weeds are cleared from land before seeds are sown and includes where some farms plow their land, clear vegetation/weeds and/or practice no or reduced forms of tillage agriculture.[4] Similarly, glyphosate has a long history of use in summer fallow for the control of a broad range of weeds in Australia.

If the use of glyphosate was prohibited in land preparation in all seven countries, the following are likely to occur in a number of crops:

- Land preparation for sowing/planting of crops is expected to be poorer—glyphosate is a key input for delivering good conditions for sowing/planting of seed in a weed-free environment;
- Land preparation costs are expected to increase because the main alternatives to glyphosate (herbicides and/or mechanical/hand weeding) are commonly more expensive;
- Poorer levels of weed control may occur because glyphosate is more effective at controlling a broader range of weeds than some of the 'knock-down' alternatives (e.g., paraquat where this is permitted for use);
- The length of time for which effective weed control is maintained may decrease, requiring additional weed control activities (e.g., additional application of other herbicides such as paraquat or glufosinate, cultural practices, hand weeding, mechanical weeding, and additional burning, notably in Indonesia and Philippines);
- Yields may decrease as a result of poorer levels of weed control (e.g., higher levels of pests and diseases vectored by aphids and nematodes harbored in summer fallow weeds);
- Some of the benefits associated with reduced/no tillage systems may be lost. Glyphosate is widely considered to be a key component to the successful adoption and maintenance of reduced/no tillage systems, which have enabled many farmers in the grain growing regions and where GM HT crop technology has been adopted to reduce their fuel and labor costs at seeding time, to improve soil conservation (less erosion), and to better manage soil moisture levels.

For crops like tropical fruit, vines, sugarcane, rubber, palm oil, tea, and coffee during the immature and mature phases of production, the expected impacts of restrictions on glyphosate use are similar to the land preparation phase with increased cost of weed control, reduced effectiveness of weed control measures, lower yields, and more pest/disease problems.

If glyphosate was no longer allowed to be used in these phases of production, the main alternatives are to switch to other methods of weed control. These are use of other herbicides or other forms of weed control.

As glyphosate is a broad-spectrum herbicide that targets control of a wide range of both broad-leaved and grass weeds, the non-glyphosate herbicide alternative method of weed control can be either use of an alternative broad-spectrum herbicide such as paraquat or glufosinate or, supplementary use of more selective herbicides at the pre-emergence phase of crop development (e.g., of trifluralin, atrazine, quizalofop). The non-herbicide alternatives include hand weeding, mechanical weed control, cultural forms of control, and the use of plowing (if no/reduced tillage is currently practiced: Table 4).

Switching to alternative herbicides was the most commonly stated action for survey respondents in Australia, Thailand, and Vietnam. Additional use of manual and mechanical weeding was also suggested by many respondents, especially in India, China, Indonesia, and Philippines. Cultural practices such as trash blanketing in sugarcane,[5] harvest weed seed control, and a reversion to plowing instead of reduced/no tillage systems may also occur in Australia.

The expected impacts of restrictions on glyphosate use in corn, canola, and cotton crops currently using GM HT technology are critical. GM HT cotton and canola were planted on all of the 270,000 hectare-cotton crop and 20% (445,000 ha) of the canola crop in Australia. GM HT corn was grown on 5% (35,000 ha) and about 30% (650,000 ha) of the corn crops in Vietnam and Philippines. All of the benefits associated with the

4. *No-till farming means that the ground is not plowed at all, while reduced tillage means that the ground is disturbed less than it would be with traditional tillage systems.*

5. *At harvesting, the leaves and tops of cane plants are left on the ground as a 'trash blanket.' This contributes to reducing soil erosion and soil water loss and provides weed control.*

Table 4. Main alternatives to using glyphosate.

Alternative herbicides	General features relative to glyphosate	Other points of relevance
Broad-spectrum 'knock down' herbicides: paraquat, glufosinate	Less effective in controlling weeds which means needing to increase frequency of application. Glufosinate also more expensive (typical twice the price of glyphosate)	Paraquat use banned in China and being phased out in Thailand and Vietnam over 3 years
Additional use of more selective herbicides pre-emergence: atrazine, acetochlor, trifluralin, 2 4 D, pendimethalin, quizalofop	Less effective in controlling weeds which means needing to increase frequency of application.	2 4 D use now banned and use being phased out over 3 years in Vietnam
Non-herbicide weed control		
Hand weeding	More expensive and increased frequency of weeding required	Harsh and poorly paid work relative to alternative employment. Requires access to pool of available labor
Mechanical weeding	More expensive and increased frequency of weeding required	Requires capital for investment in equipment/machinery
Cultural methods	More expensive and less effective	Assumes knowledge of how to use and requires capital for any equipment
Reversion to plowing (where no tillage currently practiced)	More expensive and less effective	Requires capital for investment in equipment/machinery

adoption of this technology would potentially be lost through:

- Higher costs of weed control (see below) as farmers lose out on the cost effective, less expensive and easier weed control that GM HT (tolerant to glyphosate) technology provides (e.g., Brookes & Barfoot, 2018).
- Loss of yield gains associated with better weed control. In Australia, GM HT canola seed technology has provided greatest economic advantage relative to triazine-tolerant (TT) canola and where farmers have been/are faced with weeds that are resistant to a number of non-glyphosate herbicides (e.g., annual ryegrass [*Lolium rigidum*] and wild radish [*Raphanus raphanistrum*]; Hudson & Richards, 2014). Recent National Variety Trials (NVT) data (2016) also suggests that current varieties containing the GM HT trait offer yield advantages over imidazolinone-tolerant (Clearfield) varieties. In both Philippines and Vietnam, GM HT corn has also delivered improved yields from improved weed control relative to conventional corn (Brookes & Barfoot, 2018; Gonzales, Javier, Ramirez, Cariño, & Baria, 2009).

If current GM HT cotton, canola, and corn growers could no longer use glyphosate, many are likely to switch back to using conventional seed. This will result in use of a mix of other weed control measures including other herbicides (e.g., alternative knock-down herbicides like paraquat or glufosinate and additional use of herbicides such as atrazine, trifluralin, pendimethalin, metolachlor, diuron, flumeturon, imazamox, and imazapyr), cultural practices (e.g., hand weeding, whole field cultivation, inter-row cultivation) and crop rotation (including longer fallows and pasture phases). The adoption of these measures is expected to increase costs of weed control but reduce seed costs. Any increase in cultural practices like cultivation may result in poorer levels of moisture preservation and have a negative effect on soil structure. The impact on farm income is, however expected to be negative because of likely yield losses. A switch to TT canola in Australia is likely to result in a 7%-8% yield loss and a switch to Clearfield canola, result in a 3-4% yield loss.[6] In cotton, a negative impact on yield could also arise if there is increased use of residual herbicides, because of the pre-disposition of some cotton varieties to injury, especially in cool and wet conditions. In both Philippines and Vietnam, a switch back to conventional corn is likely to result in a yield loss of about 5% (Brookes & Barfoot, 2018). Some may change to other GM HT technology where the tolerance is to other herbicides such as glufosinate (if available). This will depend on several factors, including the availability of this trait in leading varieties, possible 'stacked' availability with tolerance to other herbicides (e.g., dicamba), the cost of glufosinate, and the efficacy of glufosinate (and/or other herbicide tolerances) in controlling weeds on specific farms. Some farmers might also switch out of corn, cotton, and

6. *Based on the 2016 NVT data.*

Table 5. Example of aggregated additional direct weed-control cost impacts of restrictions on glyphosate use by crop: Vietnam.

Crop	Baseline cost using glyphosate: $/ha	Likely cost if glyphosate use no longer permitted: $/ha	Difference: $/ha	Applicable area: ha	Aggregate additional cost: '000 $
Rubber	50.91	109.38	58.47	353,100	20,646
Coffee	79.03	191.66	112.63	136,570	15,382
Rice	29.20	45.11	15.91	206,280	3,282
Tropical fruit	51.95	70.77	18.82	42,000	790
Tea	469.12	563.88	94.76	19,500	1,848
GM HT corn	51.36	89.95	38.59	55,000	2,122
Conventional corn	87.95	89.95	2.00	75,530	151

Notes: Baseline costs and changes based on survey. Applicable areas are base areas treated with glyphosate derived from Kleffmann and Kynetec and Brookes and Barfoot (2018) for GM HT corn.

canola to other crops/enterprises. For example, in Australia, cotton is currently the most profitable crop for many farmers in cotton growing regions and canola is an important and profitable break crop, grown in a rotation after cereals. This suggests that this alternative is likely to be taken up by few farms compared to the two alternatives referred to above.

Potential Economic Impacts

These potential changes to weed control practices identified in the surveys conducted for this research also identified associated costs at the hectare and farm level. These costs were then aggregated to a crop and national level by applying the per-hectare cost changes to the estimated area of each crop where glyphosate is used (based on the Kleffmann/Kynetec herbicide usage data). Table 5 provides a more detailed example of how the aggregate additional cost was estimated with reference to Vietnam.

Overall, these changes are expected to have significant financial impacts in all seven of the countries. Table 6 summarizes these impacts and points to an increase in the annual cost of direct weed control across the seven countries of between $1.36 billion and $1.88 billion, at an average increase in weed control costs of between $22/ha and $30/ha (on nearly 63 million hectares). The crops likely to experience the highest levels of additional weed control costs on a per hectare basis are plantation type crops like tea (India, China, Vietnam), oil palm (Indonesia), rubber (Indonesia, Thailand, Vietnam), and tropical/citrus fruit (China, Indonesia, India, Philippines, Thailand). In addition, relatively high additional weed control costs are expected where GM HT crop technology could no longer be used (cotton and canola in Australia, corn in Philippines and Vietnam) and where farmers switch away from no/reduced tillage cropping (Australia).

The scope for farmers implementing these weed control practice changes, especially where manual labor is expected to replace the application of glyphosate, are dependent on sufficient levels of additional labor being available for hand weeding. For example, based on the survey findings in India, where a switch to additional use of manual weeding was the main alternative to using glyphosate, the extra volume of labor required is substantial at 113 million extra days of farm labor,[7] equivalent to employing an additional 0.42 million full-time staff (equal to 6% of the level of unemployment in the agricultural workforce; source: 4th Annual Unemployment-Employment Survey 2013-14 and Indian Labor Statistics 2014 by the Labor Bureau of the Ministry of Labor and Employment). Given that hand weeding is hard physical work and poorly paid relative to alternative occupations, many farmers find it difficult to obtain (and retain) labor for such work.

A significant number of respondents to the surveys also indicated that if glyphosate use was restricted, they would expect crop yields to fall because of poorer levels of weed control. Specifically, potential yield losses were cited most frequently in relation to plantation/perennial crops where between a half and two-thirds of survey respondents growing these crops expected yield losses to arise. In addition, all growers of GM HT crops in Australia, Philippines, and Vietnam expect yield losses if they could no longer use this technology.

7. *Calculated by dividing the extra labor costs per crop hectare identified in the survey by the national minimum labor wage for agricultural labor (about $2.56/day).*

Table 6. Estimated direct weed-control cost impacts of restrictions on glyphosate use by country.

Country	Additional cost ('000 $)	Average additional cost ($/ha)	Affected area ('000 ha)
Australia	251,100-724,600	22-80	33,038
China	520,848	48	10,922
Indonesia	164,370	97	1,680
India	289,886	23	12,860
Philippines	35,180-79,084	33-74	1,075
Thailand	54,224	26	2,115
Vietnam	44,234	50	890
Total	1,359,842-1,877,246	22-30	62,580

Notes:
- *Cost estimates of additional weed control costs based on surveys conducted in each country (Columns 2 and 3).*
- *Affected area is estimated crop area treated with glyphosate—based on Kleffmann and Kynetec data and surveys (Column 4). Australia includes large areas of pasture and summer fallow land (about 23 million ha).*
- *Average additional cost: total is a weighted average*

Table 7. Impact of 1% yield loss on production and value arising from poorer weed control if glyphosate no longer allowed.

Country	Production loss: 1% yield loss ('000 tonnes)	Production loss: Main crops	Revenue/value loss: % yield loss (million $)	Value loss: Main crops
Australia	450	Canola, wheat, sugarcane	70.7	Canola, wheat
China	916	Vegetables, citrus	613.8	Vegetables, citrus
Indonesia	694	Oil palm, tropical fruit	75.9	Oil palm, tropical fruit
India	335	Fruit, sugarcane, vegetables	150.5	Fruit, vegetables, tea
Philippines	118	Corn	34.2	Corn
Thailand	207	Cassava, oil palm, rubber, sugarcane	46.3	Oil palm, rubber, tropical fruit
Vietnam	41	Corn, rubber, rice	25.5	Coffee, corn, rubber
Total			1,016.9	

Source: derived from national statistics, FAO, USDA, Kynetec and Kleffmann
Notes: Yield and producer price data 2015 annual averages from FAO and USDA data used as basis of calculating yield losses/value per ha. Aggregate volumes/values calculated relate to estimated area using glyphosate for each crop. Applicable area—estimated base areas treated with glyphosate.

It is difficult to forecast the extent to which yield losses might occur, and none of the respondents offered any forecasts of potential impact. If restrictions on glyphosate use were introduced and as a result of poorer levels of weed control resulted in yield losses, Table 7 provides an illustration of the impact of a 1% yield loss on the production and value of the main affected crops in each country.

A 1% fall in yield on the area currently using glyphosate would result in a fall of production of about 2.76 million tonnes of crops (5% yield reduction would equal about 13.8 million tonnes). In value terms, a 1% loss in yield and production on the area that currently uses glyphosate to control weeds would result in a loss of production value equal to just over $1 billion (a 5% yield loss would be equal to a value loss of about $5.08 billion).

Potential Environmental Impacts from Changes in Herbicide Use

Table 8 summarizes the use of glyphosate and herbicides in each of the seven countries (including the associated environmental impact, as measured by the EIQ indicator) and the potential impact if glyphosate use was no longer allowed. The baseline use of glyphosate active ingredient across the seven countries, in the main crops where glyphosate is used, is about 82 million kg, equal to 29% of total herbicide usage (286 million kg) on these crop.[8] Average usage of all herbicides on these

8. *Note that these values differ from those presented in Figures 1 and 2 because this section examines the main crops where glyphosate used while earlier discussion related to total glyphosate and herbicide use in each country.*

Table 8. Herbicide use on the main glyphosate using crops if glyphosate was no longer allowed (by country).

Country	Total glyphosate use ('000 kg of active ingredient)	Total herbicide use ('000 kg of active ingredient)	Average ai use (kg/ha)	Average field EIQ value/ha	Total herbicide use if glyphosate use no longer allowed ('000 kg ai)	Average ai use if glyphosate use no longer allowed (kg/ha)	Average field EIQ value/ha if glyphosate no longer allowed
Australia	23,462	60,123	0.67	13.02	50,594-78,586	0.57-0.88	12.40-18.86
China	15,255	117,567	1.60	32.23	114,168	1.55	32.86
India	14,251	38,369	0.68	12.28	26,891	0.57	11.64
Indonesia	9,071	12,381	0.78	14.50	11,606	0.73	19.55
Philippines	1,906	4,144	0.82	15.78	2,488-3,292	0.53-0.55	14.06-16.14
Thailand	15,276	45,758	2.99	52.29	41,392	2.69	53.86
Vietnam	2,745	7,720	0.78	13.72	7,005-7,957	0.72-0.81	14.80-16.92
Total of above	81,966	286,062	1.08	20.60	254,144-283,892	0.96-1.07	20.69-22.99

Sources: derived from Kleffmann, Kynetec, and in-country surveys

Notes: Columns 2-5 derived from Kleffmann and Kynetec data. Columns 6-7 derived from survey and applied to estimated area of each crop/country using glyphosate.

crops was 1.08 kg ai/ha, with an associated field EIQ/ha value of 20.6/ha.

If glyphosate use was no longer permitted, changes to herbicide use, and the associated environmental impact can be expected. The survey research identified there would be a significant shift in weed control practices based on use of alternative herbicides and/or additional use of hand and mechanical weeding. At the country level:

- ***Australia:*** Depending on the choice of alternative weed control practices taken up, there could be a net reduction in total herbicide active ingredient use of 16%, or equally a net increase in usage of 31%. In terms of the associated environmental impact, as measured by the EIQ indicator, this could lead to either a 5% reduction (environmental improvement) or a 45% increase (environmental deterioration) across the main crops/uses in which glyphosate is used. The lower end of this range represents a marginal improvement in the associated environmental impact of herbicide use compared to the current 'with glyphosate' position, while the higher end of the range represents a significant deterioration in the associated environmental impact of herbicide use compared to the 'with glyphosate' position. The lower end of this range assumes that glyphosate is replaced by paraquat as the main 'knock-down' herbicide used and no additional herbicides are used. The higher end of the usage range assumes that glyphosate is replaced by an alternative knock-down herbicide (assumed to be paraquat) plus additional herbicides (notably residual herbicides, applied pre-emergence). Given glyphosate is more effective at controlling a wider range of weeds (and for controlling larger weeds) than paraquat, it is likely that most farmers would use additional herbicides with paraquat and therefore the upper part of the range of herbicide referred to above is the more likely indicator of potential environmental impact. Overall, this suggests that if glyphosate use is no longer permitted in Australia, a majority of farmers will switch to less environmentally-friendly weed control practices. Many of the non-glyphosate-based weed control practices are also already part of existing weed resistance management strategies on many farms. Therefore, any intensification in their usage may increase the risk of weeds developing resistance to these non-glyphosate herbicides;

- ***China:*** If the area treated with glyphosate was replaced by a combination of alternative herbicides (mostly glufosinate) and other weed control practices (hand weeding), this would lead to a net reduction in total herbicide active ingredient use of about 3%. The average amount of herbicide active ingredient used for weed control (per ha) is likely to fall in most of the main crops where glyphosate is used but increase in corn. However, in terms of the associated environmental impact, as measured by the EIQ indicator, this would increase marginally (+0.4%), reflecting a marginal deterioration in the associated environmental impact of herbicide use. These potential changes in herbicide use should, however, be treated with caution because many farmers proposing to switch to glufosinate, have little or no experi-

ence of using this herbicide in weed control (glufosinate is less effective at controlling as broad a range of weeds and has poorer performance in cool conditions compared to glyphosate. Its citation as the most likely alternative to glyphosate largely reflects the recent (2016) banning on the use of paraquat which was the main alternative broad-spectrum herbicide to glyphosate). Higher usage levels, more frequent application and supplementation with other herbicides may therefore occur after initial experience of use;

- ***India:*** The most commonly cited alternatives are hand/mechanical weeding (except in corn where all producers would use other herbicides, and in tea where half of producers would use alternative herbicides—a minority of cotton, rice, fruit, and cereal growers would also make more use of other herbicides). This would result in a 30% decrease in total herbicide active ingredient use, a fall in the base area using herbicides of 17% and a 21% decrease in aggregate EIQ load associated with herbicide use. On a per hectare basis, the average amount of active ingredient usage would fall 16% because the average amount of active ingredient applied per typical application of the main alternative herbicide (paraquat) is lower than the average amount applied per hectare of glyphosate. In terms of the associated environmental impact, as measured by the EIQ indicator, the average EIQ value/ha across all crops would also fall but by less than the decrease in the amount of active ingredient applied—the average EIQ load/ha would fall by 5% only because the alternative herbicides are less environmentally benign than glyphosate and would be applied more frequently;

- ***Indonesia:*** If glyphosate was replaced by the most commonly cited alternative herbicide, paraquat, this would result in a net reduction in active ingredient use of nearly 7%. However, in terms of the associated environmental impact, as measured by the EIQ indicator, this would increase by 45%, reflecting a move to a less environmentally benign herbicide, applied more frequently. However, as some of the survey respondents indicated that hand weeding would replace glyphosate on about half of the area currently using glyphosate, a more likely outcome would be a 50% reduction in the total amount of herbicide active ingredient used and a 25% decrease in the associated environmental impact, as measured by the EIQ indicator. Additional (illegal) burning may also arise in some plantation crops;

- ***Philippines:*** If the area treated with glyphosate was replaced by alternative herbicides; paraquat in perennial crops and rice, and atrazine in corn and sugarcane, this would result in a net reduction in total herbicide active ingredient use of just over 20%. However, in terms of the associated environmental impact, as measured by the EIQ indicator, this would increase by just over 2%, reflecting a move to less environmentally benign herbicides. If the area treated with glyphosate was partly treated with other herbicides but mostly reverted to additional hand weeding, the total base area of the main crops using herbicides for weed control is expected to fall by 18%. Not surprisingly, this would lead to a significant net reduction in total herbicide active ingredient use of 40% and an 11% fall in the associated environmental impact, as measured by the EIQ indicator;

- ***Thailand:*** Replacing glyphosate with the most commonly cited alternative herbicide, paraquat (except in tropical fruit where 75% of producers would probably revert to hand/mechanical weeding), would lead to a net decrease in total herbicide active ingredient use of 10%. However, in terms of the associated environmental impact, as measured by the EIQ indicator, this would increase by 3% because paraquat is a less environmentally benign herbicide than glyphosate and would be applied more frequently than glyphosate (especially in rubber and oil palm);

- ***Vietnam:*** If the area treated with glyphosate was replaced by the most commonly cited alternative herbicides, paraquat in perennial crops and rice, and by atrazine in corn, this would result a net increase in total herbicide active ingredient use of just over 3% because of the need to spray crops more frequently with (less effective) herbicides. In terms of the associated environmental impact, as measured by the EIQ indicator, this would increase by 23%, reflecting a move to less environmentally benign herbicides than glyphosate. If the area treated with glyphosate was partly treated with other herbicides and partly reverted to additional hand and mechanical weeding (as indicated by some survey respondents), the total base area of the main crops using herbicides for weed control would be expected to fall marginally (by 2%). This would lead to a net

reduction in herbicide use of 9%. The associated environmental impact, as measured by the EIQ indicator, would increase by 8% because of the additional use of less environmentally benign herbicides.

Across the seven countries, Table 8 suggests that a ban on the use of glyphosate would result in a reduction in the total amount of herbicide active ingredient used (-1% to -11%). In terms of the associated environmental impact, as measured by the EIQ indicator, there would however be a poorer environmental outcome, with the average EIQ/load per ha increasing by between a small 0.4% and a more significant 11.6%.

It should be noted that where survey respondents in each country indicated they would switch to weeding by hand, sufficient labor would have to be found and hired to undertake this work. As indicated above, the additional labor requirement may be substantial (e.g., in India) and would likely prove difficult to secure. This means that the inferred environmental changes associated with significant reductions in herbicide use discussed above may not arise especially if farmers end up examining alternative herbicide-based solutions not yet considered.

A second potential environmental impact relates to possible loss of some of the benefits of no/reduced tillage agriculture. These include reduced levels of soil erosion, higher levels of soil water content, and reduced levels of greenhouse gas emissions (e.g., Conservation Technology Information Center, 2002; Fabrizzi, Morón, & García, 2003). If farmers currently practicing no/reduced tillage production systems are no longer able to use glyphosate for weed control and cannot use the 'next best' (but nevertheless less effective) alternatives (atrazine, paraquat), many may find that is difficult to maintain no/reduced tillage systems and revert to a plow-based system.

Conclusions

Glyphosate is widely used around the world for weed control in conventional agriculture and is a key part of the production system that uses GM HT crop technology. Total global annual use of glyphosate is in the range of 450 to 500 million kilograms of active ingredient, of which the seven countries in Asia examined in this study use about 16%-18% of the global total. Glyphosate is widely used in land preparation before the planting of a crop, in both seasonal and plantation-type crops. It is an important component for in-crop and in-between crop weed control in conventional crops and is a key part of weed control in GM HT (tolerant to glyphosate) crops grown in three of the Asian countries examined (corn in Philippines and Vietnam, canola and cotton in Australia), even though these three countries account for only 1% of GM HT crops grown globally.

If restrictions on the use of glyphosate, in the form of a ban on agricultural use were introduced in the seven countries, the expected impacts are likely to be significant. The main impacts are likely to be higher weed control costs, poorer levels of weed control, reduced time of effective levels of weed control, increased incidence of pests, lower yields, poorer access to fields, loss of the benefits associated with no and reduced tillage and loss of benefits associated with the adoption of GM HT crops (benefits of lower costs of production and higher yields: see Brookes et al., 2017, and Brookes & Barfoot, 2018). The ease or otherwise of replacing glyphosate with alternatives will be strongly dependent on local factors such as the share of crop production in which glyphosate is used for weed control, the crop and field-specific impact on levels of weed control, availability and cost of mechanical alternatives, and labor. These will be highest on farms using GM HT technology and amongst conventional growers of fruit, vegetables, and plantation crops, where glyphosate is widely used for weed control between crops.

There is likely to be more use of alternative herbicides and additional use of manual, mechanical, and cultural weed control methods. These changes are expected to increase the annual cost of weed control across the seven countries by between $1.36 billion and $1.88 billion, at an average increase in weed control costs of between $22/ha and $30/ha. This represents a sizable increase in costs of production and a loss of competitiveness, which would be exacerbated where lower yields arise and where one of the main alternative herbicides cited for use (paraquat) is being withdrawn from use (e.g., in Vietnam). In relation to the environmental impact associated with herbicide use, while the changes in weed control practices are likely to result in a small decrease in the total amount of herbicide active ingredient used across the seven countries (-1% to -11%), in terms of the associated environmental impact, as measured by the EIQ indicator, the average EIQ load/ha would increase by between 0.4% and 11.6%, highlighting a poorer environmental outcome. This is because the alternative herbicides likely to be used are less environmentally benign than glyphosate and would be applied more frequently. A loss of some of the benefits of no/reduced tillage agriculture practiced by some farmers may also occur. These 'lost' benefits include reduced

levels of soil erosion, higher levels of soil water content and reduced levels of greenhouse gas emissions. Additional (illegal) burning may arise in plantation crops. Lastly, where farmers indicated they would make more use of hand weeding, this would require employment of significant volumes of additional labor. This may well prove difficult to implement, given the harsh nature of such work and low levels of pay compared to alternative occupations. The inferred reductions in herbicide use referred to above may therefore not arise, if farmers are forced to re-examine alternative herbicide-based solutions not yet considered. A lack of labor to undertake additional hand weeding would also make significant yield and production value losses more likely to occur.

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Statistical Sources

Kleffmann and Kynetec are subscription-based data sources (derived from farmer surveys and expert—industry and extension—assessment of herbicide sales data and knowledge of farm-level weed-control practices) on pesticide use. The annual Unemployment-Employment Survey 2013-14 and Indian Labor Statistics 2014 by the Labor Bureau of the Ministry of Labor and Employment (Government of India) was also used.

Appendix 1: Survey Sample Selection

Table A1. India: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Cereals	28	46 (29%)	Corn and wheat
Cotton	26	15 (9%)	
Fruit	22	36 (22%)	Citrus, pomegranate, grapes
Vegetables	12	17 (11%)	Ginger, chilli, brinjal, tomato
Rice	6	26 (16%)	
Sugarcane	1	10 (6%)	Plantation
Others	5	10 (6%)	Tea (plantation)

Notes: Target number of interviews 160-170 (limit based on budget available). Interviews were 139 with farmers and 21 with advisors and pesticide dealers/wholesalers. Farmers in relation to crops of sugarcane and tea includes plantation (in-house/employed) agronomists. Others: included non-agricultural uses (e.g., roadside verges). Interviews conducted June-August 2017.

Table A2. Vietnam: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Rubber	57	13 (22%)	Plantation
Corn	3	16 (27%)	Including 5 using GM HT corn which accounts for 3% of total crop
Tropical fruit	4	9 (15%)	Jackfruit, durian, longan
Coffee	12	8 (14%)	Plantation
Rice	9	3 (5%)	
Others	15	10 (17%)	Avocado, sugarcane and non-agricultural uses

Notes: Target number of interviews 50-60 (limit based on budget available). Interviews were with 54 with farmers (private and collectives) and 5 with advisors. Farmers in relation to crops of rubber and coffee includes plantation (in-house/employed) agronomists. Interviews conducted September-November 2016.

Table A3. Thailand: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Rubber	35	23 (14%)	Plantation
Additional (plantation) crops	34	25 (15%)	Tamarind, durian, jackfruit
Oil palm	11	11 (7%)	Plantation
Cassava	4	16 (10%)	
Mango	4	20 (12%)	Plantation
Sugarcane	2	22 (14%)	Plantation
Rice	2	8 (5%)	
Others	7	36 (22%)	Other fruit and vegetables

Notes: Target number of interviews 160-170 (limit based on budget available). Interviews were 155 with farmers and 6 with advisors. Farmers in relation to crops of rubber, oil palm and sugarcane includes plantation (in-house/employed) agronomists. Interviews conducted April-June 2017.

Table A4. Indonesia: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Oil palm	63	19 (26%)	
Rice	11	12 (17%)	
Corn	7	12 (17%)	
Non-crop use	6	7 (10%)	Forestry clearance
Tropical fruit	3	7 (10%)	
Rubber	4	10 (14%)	
Other crops	6	5 (7%)	Sugarcane, coffee, bananas

Notes: Target number of interviews 75 (limit based on budget available). Interviews were with 67 farmers (private and collectives) and 5 with advisors/distributors. Farmers in relation to crops of oil palm, rubber, sugarcane and tropical fruit includes plantation (in-house/employed) agronomists. Interviews conducted July-October 2016.

Table A5. China: Glyphosate user survey—Sample selection.

Crop	% of total glyphosate use (by weight of active ingredient)	Interview undertaken (% of total in brackets)	Notes
Citrus fruit	20	15 (18%)	Mandarins, pears, apples
Rice	12	15 (18%)	
Tea	9	8 (10%)	
Vegetables	9	9 (11%)	Garlic, brassicas
Corn	9	9 (11%)	
Other fruit	14	5 (6%)	Banana
Cotton	5	9 (11%)	
Other crops and uses	22	14 (14%)	Canola, peanuts, forestry

Notes: Target number of interviews 90 (limit based on budget available). Interviews were 76 with farmers (private and collectives) and 5 with advisors. Farmers in relation to crops of tea and bananas includes plantation (in-house/employed) agronomists. Interviews conducted February to April 2017.

Table A6. Australia: Glyphosate user survey.

Crop	% of total glyphosate use (by weight of active ingredient)	Interviews undertaken	Notes
Non-crop use/fallow	53	See notes	Mostly for weed control in fallow—data from Canola survey and GRDC weed management guide
Cereals	22	2 advisors plus see notes	As above
Forage crops	14		As above
Cotton	5	179	Crop entirely GM HT (tolerant to glyphosate)
Canola	3	152	20% of crop is GM HT (tolerant to glyphosate). Almost all of the rest of crop is HT using conventional technology (e.g., triazine tolerance)
Others	3	49	Agronomists and growers of sugarcane, temperate fruit, tomatoes, capsicum, brassicas, celery, zucchini, melons, and grapes

Notes: Basis of research different to other countries. Combination of existing literature (weed management guides), crop-specific (cotton and canola) weed/resistance management surveys of growers plus some interviews (with questionnaire used in other countries). Interviews conducted August-December 2016.

Appendix 2: Baseline Cost of Herbicides and Cost of Glyphosate

Table A7. China.

Crop	Average cost of herbicides $/ha	Average cost of glyphosate where used $/ha	Notes
Bananas	95	32	Weed control based on combination of mechanical, hand weeding and herbicides. Glyphosate, where used, in land preparation and in-between crop weed control
Citrus fruit	61	22	As bananas
Rice	27	38	Weed control based on combination of mechanical, hand weeding and herbicides. Glyphosate, little used and only in land preparation
Tea	36	30	As bananas
Vegetables	20	18	As bananas
Corn	32	18	As rice
Cotton	46	22	As rice
Canola	17	19	As corn

Notes: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec). Glyphosate use in land preparation typically a single application and where used in between crops during growing season typically 2-3 applications.

Table A8. Australia.

Crop	Average cost of herbicides $/ha	Average cost of glyphosate where used $/ha	Notes
Fallow	8	7	Weed control based on combination of mechanical/no-tillage and herbicides. Glyphosate typically used once for general weed control
Pasture	9	8	Weed control based on combination of mechanical and herbicides. Glyphosate typically used once for land preparation before sowing
Vines	127	16	Weed control based on combination of mechanical, cultural and herbicides. Glyphosate, used in land preparation and between crop (in season) weed control (once/twice per season)
Cereals	20-24	7-10	As pasture
Tropical fruit	72	8	Weed control based on combination of mechanical and herbicides. Glyphosate, used in land preparation and between crop (in season) weed control (once/twice preseason)
Sugarcane	64	8	As tropical fruit
Canola	27	10	Glyphosate used for land preparation in conventional HT crops and for land preparation and over the top spraying in GM HT crop (2 applications in GM HT in total)
Cotton	101	27	Glyphosate used for land preparation and over the top spraying in GM HT crop (3-4 applications in total)

Note: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources Kleffmann/Kynetec).

Table A9. Indonesia.

Crop	Average cost of herbicides (excluding application cost) $/ha	Average cost of weed control $/ha	Notes
Oil palm	27	18	Weed control based on combination of mechanical, hand weeding and herbicides. Glyphosate widely used, in land preparation and in-between crop weed control (2-3 applications)
Rice	7	2	Weed control based on combination of mechanical, hand weeding and herbicides. Glyphosate, little used and only in land preparation
Corn	39	16	Weed control based on combination of mechanical, hand weeding and herbicides. Glyphosate used mostly in land preparation
Land reclamation	23	18	Mainly manual weeding and herbicides used. Glyphosate is the most commonly used herbicide, typically twice
Rubber	23	12	As oil palm, except 1-2 in-crop treatments
Sugarcane	19	4	As corn—mostly used in land preparation
Tropical fruit	21	16	As corn but also some use in-crop

Note: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec).

Table A10. India.

Crop	Average cost of herbicides (excluding application cost) $/ha	Average cost of weed control $/ha	Notes
Cereals	9	10	Weed control based on mostly mechanical and hand weeding plus some (limited) use of herbicides. Glyphosate, where used, is only in land preparation
Rice	10	6	As cereals
Corn	7	13	As cereals
Tea	24	20	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate widely used in land preparation and between crops (2-3 applications)
Cotton	11	10	As cereals
Sugarcane	10	12	As cereals
Fruit	9	14	As cereals
Vegetables	11	12	As fruit but some additional use of glyphosate in between crops in growing season

Note: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec).

Table A11. Philippines.

Crop	Average cost of herbicides (excluding application cost) $/ha	Average cost of weed control $/ha	Notes
Bananas	38	37	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate widely used in land preparation and between crops (2-3 applications)
Corn	33	22	Glyphosate used for land preparation (LP) only in conventional corn. Used for LP and over the top treatment in GM HT crop
Non-crop use	37	39	Glyphosate dominates weed control in non-crop use with up to 4 applications per year
Rice	21	18	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate widely used in land preparation
Rubber	41	34	As bananas
Sugarcane	52	35	As bananas
Tropical fruit	58	41	As bananas

Note: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec).

Table A12. Thailand.

Crop	Average cost of herbicides (excluding application cost) $/ha	Average cost of weed control $/ha	Notes
Cassava	22	15	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate widely used in land preparation and between crops (2 applications)
Corn	25	14	Herbicides are main form of weed control, with some use of hand weeding. Glyphosate, where used, is mostly for land preparation
Mango	27	30	As cassava, except glyphosate commonly used 3 times per growing season
Rambutan	37	44	As cassava, except glyphosate commonly used 3 times per growing season
Rubber	36	38	As cassava, with glyphosate most used herbicide—3-4 times per growing season
Oil palm	39	37	As rubber
Rice	28	9	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate only used in land preparation
Sugarcane	72	17	As rice, though glyphosate sometimes used in-crop (2 applications in total)
Citrus	93	60	As mango and rambutan

Note: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec).

Table A13. Vietnam.

Crop	Average cost of herbicides (excluding application cost) $/ha	Average cost of weed control $/ha	Notes
Coffee	17	15	Weed control based on mostly mechanical and hand weeding plus use of herbicides. Glyphosate widely used in land preparation and between crops (2 applications)
Corn	15	14	Mix of hand/mechanical weeding and use of herbicides. Glyphosate, where used in conventional corn is for land preparation. In GM HT corn, used ‘over the top’ (1-2 applications)
Rice	30	10	Mix of hand/mechanical weeding and use of herbicides. Glyphosate, where used in conventional corn is for land preparation
Rubber	33	29	As coffee
Sugarcane	18	28	Hand weeding and use of herbicides are main form of weed control. Glyphosate mostly used (1 application) in land preparation
Tea	33	27	As coffee
Tropical fruit	52	22	As coffee

Notes: Average cost of herbicides and glyphosate are per base area, excluding application cost (sources: Kleffmann/Kynetec and survey).

Appendix 3: Questionnaire

Glyphosate use research project: Benefit of glyphosate in agricultural crops/uses

Answers to the questions below are vital to this research. Please complete with as much detail and consideration as possible.

All responses will be treated confidentially and no individual responses will be used in the final document. The data/answers provided will be used only to compile a crop-specific and aggregated assessment of possible impacts.

Questions are laid out below in relation to three possible phases when glyphosate might be used: in land preparation before planting, in the immature crop phase (mostly relating to plantation/fruit crops) and the mature crop phase.

1 Name: _____

2 Crop/use being discussed:_____

3 Type of organization:_____ (e.g., farm, plantation, farm adviser)

4 For your most used glyphosate product, how many grams per litre or kg of active ingredient are used? Select only one.

5 What agronomic operation(s) do you use glyphosate on? You may select more than one option.

No/minimum tillage land preparation In crop weed control

Others, please specify _____

Glyphosate use for land preparation/pre-planting in field crops, sugarcane, oil seeds, cereals, cotton, non crop use

6 If you use glyphosate in land preparation what are the main types of weed you want to control?

(select only the common and major weeds)

Grasses, please give common names_____

Broadleaf, please give common names_____

Sedges, please give common names_____

Fern, please give common names_____

Others, please specify_____

7 How many litres of glyphosate do you apply per hectare to control weeds? (if this varies by type of weed please give more than one answer) _____ Glyphosate in land preparation (lt/ha as product rate)

8 Do you mix glyphosate with other herbicides?

No, use only glyphosate Yes, mix with other herbicide(s)

9 If yes to mixing with other herbicides, what kind of mix do you use?

Pre-mix - if you buy the herbicide with glyphosate as a ready-mixed product

Tank-mix - if you use glyphosate and add the other herbicide in your spray tank before application

10 What is/are the active ingredient(s) of the additional herbicide you mix? (name of product/herbicide) _____

11 What is the approximate cost of your glyphosate herbicide application per hectare?_____

13 What impact(s) do you think there will be if you could no longer use glyphosate. Several answers are allowed

1 Land preparation will not be optimal
2 Yield will decrease
3 Increased problem of pests and diseases
4 Poorer weed control
5 Land preparation cost will increase
6 Weeds will compete more
7 Access to fields will be more difficult
8 The effective weed control cycle will be shorter

Other, please describe: _____

Appendix 3: Questionnaire

14 If you can no longer use glyphosate, what other weed control method will you use? Please describe.

_____

15 What is the cost of the alternative methods of land preparation?

	Other method/herbicide/ hand weeding	Cost (local currency/ha)
Cost of other herbicides (e.g., cost of herbicide)		
Cost of labourer/application per ha		
Total cost		

GLYPHOSATE USE IN PERENNIAL CROPS - this section applies mostly to orchards, plantation (e.g., rubber), fruit crops

17 If you use glyphosate on perennial crops what are the main weeds you aim to control?

(select only the common and major weeds)

Grasses, please give common names_____

Broadleaf, please give common names_____

Sedges, please give common names_____

Fern, please give common names_____

Others, please specify_____

18 How many litres of glyphosate do you apply per hectare to control weeds? (if this varies by type of weed, please give more than one answer) _____

19 Do you mix glyphosate with other herbicides?

No, use only glyphosate Yes, mix with other herbicide(s)

20 If yes, what kind of mix do you use?

Pre-mix - if you buy the herbicide with glyphosate as a ready-mixed product

Tank-mix - if you use glyphosate and add the other herbicide in your spray tank before application

21 What is/are the active ingredient(s) of the additional herbicide you mix? (list below name of product/herbicide)

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

22 What is the cost of one application/treatment (USD/ha)? _____

Cost of herbicide (local currency/ ha)

Cost of labourer/application per ha (local currency/ ha)

Total cost per ha (local currency/ ha)

23 How many applications do you make per year? _____

Also state how many years/cycle _____

24 What is the total cost per application/hectare? local currency _____

25 What is the total cost per hectare? local currency _____ total cost = cost of application x number of application

26 What impact(s) do you think there will be if you could no longer use glyphosate. Several answers are allowed.

1 Poorer weed control

2 Weed control cost will increase

5 Immature crop growth will not be optimal

6 Weeds will compete more with immature crop to get fertilizer

Appendix 3: Questionnaire

3 Yield will decrease
4 Access to fields will be more difficult
7 Increased problem of pests and diseases
8 The effective weed control cycle will be shorter
Other, please describe: _____

27 If you can no longer use glyphosate, what other weed control method will you use? Please describe.

_____

28 What is the cost of the alternative methods of weed control? (per application local currency/ha) _____

	Other method/herbicide/ hand weeding	Cost (local currency/ha)
Cost of other herbicides (e.g., cost of herbicide)		
Cost of labourer/application per ha		
Total cost		

29 How many applications will you expect to make? _____
(please state in relation to the length of the perennial crop production phase)?

30 What is the total cost per year: applic cost x number of treatments local currency/ha _____

Glyphosate Use in Field Crops (e.g., cereals, oilseeds)

31 If you use glyphosate in field crops, what are the main weeds you aim to control?
(select only the most common and major weeds)
Grasses, please give common names_____
Broadleaf, please give common names_____
Sedges, please give common names _____
Fern, please give common names_____
Others, please specify_____

32 How many litres of glyphosate do you apply per hectare to control these weeds? (if this varies by type of weed, please give more than one answer) _____

33 Do you mix glyphosate with other herbicides?
No, use only glyphosate
Yes, mix with other herbicides

34 If yes, what kind of mix do you use?
Pre-mix - if you buy the herbicide with glyphosate as a ready-mixed product
Tank-mix - if you use glyphosate and add the other herbicide in your spray tank before application

35 What is/are the active ingredient(s) of the additional herbicide you mix? (list below name of product/herbicide)

_____ litre or kg/ha
_____ litre or kg/ha
_____ litre or kg/ha
_____ litre or kg/ha
_____ litre or kg/ha
_____ litre or kg/ha

36 What is the cost of one application/treatment (local currency/ha)?

	Single glyphosate option	Mix option
Cost of herbicide (local currency/ha)		
Cost of labourer/application per ha (local currency/ha)		
Total cost per ha (local currency/ha)		

Appendix 3: Questionnaire

37 How many applications do you make per year? _____

38 Total cost per year: Local currency _____

40 What impact(s) do you think there will be if you could no longer use glyphosate. Several answers are allowed.

Poorer weed control	Crop growth will not be optimal
Weed control costs will be increase	Weed will compete more
Yield will decrease	Increased problem of pests and diseases
Access to fields will be more difficult	The effective weed control cycle will be shorter

Other, please describe: _____

41 If you can no longer use glyphosate, what other weed control method will you use? Please describe.

_____

42 What is the cost of the alternative methods of weed control?

	Alt. weed control option (e.g., other herbicide)	Cost (local currency/ha)
Cost of other alternative product (e.g., herbicide)		
Cost of labourer/application		
Total cost		

43 How many applications will you expect to make? _____

44 What is the total cost per year: applic cost x number of treatments local currency/ha _____

GLYPHOSATE USE IN NON CROPS/NON AGRICULTURAL USES - OTHER THAN FOR LAND PREPARATION

45 If you use glyphosate for a non-agricultural use, what is this use and what are the main weeds you aim to control? If this use is only for land preparation and you have already answered questions above relating to land preparation, please ignore this section.

a) What is the non agricultural use? _____

b) What are the main weeds you aim to control? (select only the most common and major weeds)

Grasses, please give common names _____

Broadleaf, please give common names _____

Sedges, please give common names _____

Fern, please give common names _____

Others, please specify _____

46 How many litres of glyphosate do you apply per hectare to control these weeds? (if this varies by type of weed, please give more than one answer) _____

47 Do you mix glyphosate with other herbicides?

No, use only glyphosate

Yes, mix with other herbicides

48 If yes, what kind of mix do you use?

Pre-mix - if you buy the herbicide with glyphosate as a ready-mixed product

Tank-mix - if you use glyphosate and add the other herbicide in your spray tank before application

Appendix 3: Questionnaire

49 What is/are the active ingredient(s) of the additional herbicide you mix? (list below name of product/herbicide)

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

50 What is the cost of one application/treatment (local currency/ha)?

	Single glyphosate option	Mix option
Cost of herbicide (local currency/ha)		
Cost of labourer/application per ha (local currency/ha)		
Total cost per ha (local currency/ha)		

51 How many applications do you make per year? _____

52 Total cost per year: Local currency _____

53 What impact(s) do you think there will be if you could no longer use glyphosate? Several answers are allowed.

Poorer weed control

The effective weed control cycle will be shorter

Weed control costs will be increase

Weed will compete more

Other, please describe:

54 If you can no longer use glyphosate, what other weed control method will you use? Please describe.

_____

55 What is the cost of the alternative methods of weed control?

	Alt. weed control option (e.g., other herbicide)	Cost (local currency/ha)
Cost of other alternative product (e.g., herbicide)		
Cost of labourer/application		
Total cost		

56 How many applications will you expect to make? _____

57 What is the total cost per year: applic cost x number of treatments local currency/ha_____

GLYPHOSATE USE IN ROUNDUP READY CORN (PHILIPPINES ONLY)

58 How many applications of glyphosate do you use on Roundup Ready corn and when do you apply them (e.g., early stage of crop growth, matrure stage of crop growth)

Number of applications _____

Stage of growth for applications (list)

59 Do you use no or reduced tillage with Roundip Ready corn? Yes No

60 How many litres of glyphosate do you apply per hectare in each application?

Application one _____

Application two (if applicable) _____

Application three (if applicable) _____

61 Do you mix glyphosate with other herbicides?

No, use only glyphosate

Yes, mix with other herbicides

Appendix 3: Questionnaire

62 If yes, what kind of mix do you use?

Pre-mix - if you buy the herbicide with glyphosate as a ready-mixed product

Tank-mix if you use glyphosate and add the other herbicide in your spray tank before application

63 What is/are the active ingredient(s) of the additional herbicide you mix? (list below name of product/herbicide)

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

_____ litre or kg/ha _____ litre or kg/ha

64 What is the cost of one application/treatment (local currency/ha)?

	Single glyphosate option	Mix option
Cost of herbicide (local currency/ ha)		
Cost of labourer/application per ha (local currency/ ha)		
Total cost per ha (local currency/ ha)		

65 How many applications do you make per year? _____

66 Total cost per year: Local currency _____

67 What impact(s) do you think there will be if you could no longer use glyphosate and Roundup Ready corn? Several answers are allowed.

Grow conventional corn

Grow a different crop (state which one)

Leave land uncultivated

It will make it more difficult to continue with reduced/no tillage

May have to stop using no/reduced tillage and start ploughing again

Use land for a different agricultural activity (e.g., livestock)

Other, please describe: _____

68 If you can no longer use Roundup Ready corn and you switch to conventional corn or a different crop, what weed control methods will you use? Please describe. _____

69 What is the cost of the alternative methods of weed control?

	Alt. weed control option (e.g., other herbicide)	Cost (local currency/ha)
Cost of other alternative product (e.g., herbicide)		
Cost of labourer/application		
Total cost		

70 How many applications will you expect to make? _____

71 What is the total cost per year: applic cost x number of treatments local currency/ha _____

Thanks for your cooperation to participate in this survey. Your input is very valuable.