QUANTIFYING THE ECONOMIC AND ENVIRONMENTAL BENEFITS OF PARAQUAT

Jonathan Shoham outlines the benefits associated with the use of paraquat

Keywords; Paraquat, Gramoxone, economic benefits, farmer incomes, crop revenues, crop yields, labour costs weed control costs, land preparation costs, soil erosion, no-till, Vietnam, Philippines, China

Introduction

Much has been written about the benefits of paraquat (Brown *et al*, 2004), currently the world's second largest herbicide in sales terms (Phillips McDougall, 2013). It was introduced in 1962 by ICI and is now used in almost 100 countries and by an estimated 25 million, mainly small, farmers. However, previous examinations have tended to focus on the environmental benefits, such as reduced soil erosion in no-till situations, and been qualitative in nature. This paper looks at the economic and environmental benefits, quantifying them as far as possible in monetary terms and scaling them up to reach an approximate global estimate of the economic benefits. It pulls all available economic benefits information on paraquat together, but builds particularly on two recent country case studies and also considers some new and increasingly topical aspects not addressed before such as soil microbial activity.

Methodology

Two recent detailed studies which take different approaches to looking at the benefits of paraquat are used as the basis for this paper: a series of trials on maize and tea in Vietnam which looked at both the economic and environmental benefits of paraquat, and a farmer survey conducted in the Philippines in 2011 which looked at the farmer incomes across 6 crops on which paraquat is used and specifically compared the costs of weed control between users and non-users of paraquat. The results of these were then cross-referenced with some older studies from China and scaled up where possible to obtain a global estimate of economic benefits.

The Vietnamese study (Tin *et al*, 2011) comprised a trial conducted by the Northern Mountainous Agricultural and Forestry and Science Institute (NOMAFSI) between 2006 and 2010 which compared conventional farmer practice of hand weeding and burning crop residues with no-till systems based on paraquat and glyphosate and looked at the following parameters:

Weed control in terms of number of species and weed densities
Crop yields
Soil fertility, including levels of organic matter, phosphorus, potassium and the cationic exchange capacity
Soil microbial activity
Soil erosion
Farmer incomes

The Philippines study (Quicoy *et al*, 2012) was a questionnaire-based survey of just under 500 farmers who between them grow cabbage, Chinese cabbage, eggplant, potato, sugar cane and maize, conducted by researchers from the University of the Philippines, Los Banos. Focus group discussions with farmers and government officials were also conducted. The study looks at the revenues, costs of production and incomes of users and non-users of paraquat. It splits out production costs as follows:

Hired labour costs	Material costs
Land preparation	Seeds
Weeding	Paraquat
Spraying	Other herbicides and crop protection agents
Harvesting	Fertilizers
Planting	
Fertilizer application	
Paraquat spraying	

As such it provided valuable data on the overall production economics of small farmers in an emerging market, which is often very difficult to come by.

These two surveys provide some benchmarks for yield increases and labour cost savings from using paraquat which can then be compared with data from other countries.

Results

Vietnam

There are around 10 million small farmers each with less than 2 hectares of arable land in Vietnam, supporting an average of 4 family members. The total land area under permanent and arable crops is 9.5 m hectares, giving on average 0.11 hectares per head of population, which is low by global standards[1]. Given the mountainous nature of the country, a high proportion of the land – two-thirds – is sloping and 40% is susceptible to soil erosion. This is exacerbated by the relatively high level of precipitation in the country, which averages around 3000 mm/year, and extensive ploughing of the land. In some areas, up to 150 tonnes of soil per hectare is lost a year and losses of over 50 tonnes a year are common. This is high by

1 The FAO estimates the global average is around 0.2 hectares of arable per person.

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global standards (Pimental et al, 1995). These conditions play to paraquat's strengths of suitability for use in no-till systems, and rain-fastness.

Vietnam has greatly improved agricultural productivity in recent years and is a major agricultural producer. It is a significant exporter of rice, coffee, tea, cashews and cassava. The one crop which it produces where it has a significantly negative trade balance is corn, demand for which as an animal feed has been growing.

Table 1 shows the yield benefits for maize and tea from the NOMAFSI study. Yields in the system using paraquat are increased 18% and 13% for maize and tea respectively compared to conventional practice. The increases compared to glyphosate-based systems are 3% and 8% respectively. Such yield increases go directly through to the farmer's 'bottom line'.

Table 2 compares the different production systems in terms of their impact on key factors which can affect crop yields: weed control, soil fertility, soil microbial activity and soil erosion. The paraquat-based system beneficially impacts all of these factors leading to significantly improved weed control, soil fertility, levels of soil microbial activity and reduced soil erosion compared to conventional practice and lower, but still very significant, levels of improvement on weed control, soil microbial activity and soil erosion compared to glyphosate use. The main reason for these results compared to glyphosate is the mode of action of paraquat, which, being a contact, non-translocated herbicide leaves the weed roots intact, thus helping preserve both soil structure and host plants for biodiversity.

Another important factor in increasing yields is the advancement of planting which paraquat facilitates. Because of its speed of action and lack of soil residual effect, crops can be planted within 2 days of paraquat being used to clear the land. This is 8 days more quickly than in the case of the more

Table 1. Yields of maize and tea in conventional, paraquat- and glyphosate-based systems in Vietnam.

Crop	Yield: tonnes/ha			Yield advantage of paraquat cf	
	Conventional system	Paraquat	Glyphosate	Conventional	Glyphosate
Maize	3.87	4.56	4.43	17.8%	2.9%
Tea	4.35	4.9	4.55	12.6%	7.7%

Table 2. Comparison of weed control, soil erosion and soil quality between conventional, paraquat- and glyphosate-based systems in Vietnam.

Area	Parameter	Conventional system	Paraquat	Glyphosate	% Difference between paraquat and Conventional	% Difference between paraquat and Glyphosate
Weed control - maize	Number of weed species observed	14	9	11	–35.7	–18.2
	Total amount of weeds: kg/ha	3672	2014	2356	–45.2	–14.5
Weed control - tea	Number of weed species observed	18	7	13	–61.1	–46.2
	Total amount of weeds: kg/ha	4850	2215	3450	–54.3	–35.8
Soil fertility – all plots	pH KCl	4	5.74	5.31	43.5	8.1
	OM %	0.75	2.81	2.6	274.7	8.1
	P_2O_5 available %	5.2	10.41	9.98	100.2	4.3
	K_20 available %	7.98	13.36	11.06	67.4	20.8
	CEC (Ldl/100g soil)	8.15	10.8	10.7	32.5	0.9
Soil microbial activity - all plots	Nitrogen fixed: CFU/g	34000	570000	140000	1576.5	307.1
	Phosphate: CFU/g	320000	1160000	790000	262.5	46.8
	Cellulose: CFU/g	200000	2530000	290000	1165.0	772.4
	Total microbial: CFU/g	260000	4580000	2850000	1661.5	60.7
	Total fungi: CFU/g	80000	249000	245000	211.3	1.6
Soil erosion – maize	Eroded soil: tonnes/ha	36.46	15.39	24.34	–57.8	–36.8
Soil erosion – tea	Eroded soil: tonnes/ha	30.25	13.5	22.8	–55.4	–40.8

slow-acting glyphosate and around 2 weeks earlier than for the much more time-consuming mechanical land preparation. Other studies have shown a significant positive yield response to earlier planting (Iowa State University, 2001).

Farmer income data from the Vietnamese trial, displayed in Table 3, show that in addition to increased revenue, deriving from and in line with improved yields, there are also cost savings from reduced labour requirements. These save of the order of $140–190/ha. This is partially offset by the additional cost of the herbicide, but still results in a net farmer income benefit of $90/ha for maize and $380/ha for tea.

Assuming a daily wage in rural Vietnam of around $3, these labour costs savings equate to a reduction in labour of around 40–65 days versus conventional tillage. These are in line with the results from an earlier study (Table 4 Tin *et al*, 2008) which looked in more detail at the labour savings and showed that compared to conventional practice use of paraquat could save 80 days labour per hectare. These savings are also in line with other estimates of the time it takes to hand weed one hectare once (Gianessi, 2009).

In this earlier study, the yield benefits were found to be greater compared to both conventional practice and glyphosate-based systems, leading to an overall income benefit of round $250/ha compared to conventional practice.

Table 3. Farmer incomes in conventional and paraquat-based systems in Vietnam.

	Conventional system: $/ha	**Paraquat** S/ha	**Difference between paraquat and conventional system** $/ha	%
Maize				
Income	1129.8	1318.1	188.3	16.7%
Labour cost	335.1	196.8	–138.3	–41.3%
Paraquat cost	0.0	239.4	239.4	
Fertilizer and other herbicide cost	442.8	442.8	0.0	0.0%
Total production cost	777.9	879.0	101.1	13.0%
Profit	351.9	439.1	87.2	24.8%
Tea				
Income	4042.6	4468.1	425.5	10.5%
Labour cost	2058.5	1865.3	–193.2	–9.4%
Paraquat cost	0.0	239.4	239.4	
Fertilizer and other herbicide cost	1517.6	1517.6	0.0	0.0%
Total cost	3576.1	3622.2	46.1	1.3%
Profit	466.5	845.9	379.4	81.3%

Table 4. Farmer revenues, costs and income from maize in different production systems: Vietnam 2008.

	Conventional	**Glyphosate/ no-till**	**Paraquat/ no-till**
Yield: tonnes/ha	2.5	2.8	3.9
Corn price: $/tonne	260	260	260
Revenue: $/ha	656.8	730.9	1027.5
Labour: man-days/ha	220	150	140
Production costs: $/ha	557.2	481.4	678
Profit: $/ha	99.6	249.6	349.6

Source: Tin *et al*, 2008.

These yield benefits apply principally to a sloping area of 500,000 ha of corn in the North West and central highlands of Vietnam. Scaling them up based on a paraquat market share of 20%, according to company sources, gives an overall benefit of between $8m and $25m, depending on the farmer income benefit obtained (i.e. $80/ha or $250/ha, over the paraquat use area of 100,000 hectares)

An additional benefit is derived from import substitution. As paraquat increases yields by anything from 0.1 to 1.1 tonnes/hectare compared to glyphosate and 0.7 to 1.4 tonnes/hectare compared to traditional methods, were it not to be used there would be a resultant need for an additional 10,000–140,000 tonnes of maize at an approximate cost to the country of $3–36m, assuming a maize price of $260/tonne.

Paraquat usage data for tea in terms of the number of hectares sprayed is not available so it is not possible to calculate the commensurate absolute benefit in the case of that crop, although the relative, per hectare benefits are greater.

A further environmental benefit from paraquat derives from its use in land preparation where it can substitute for the alternative practice of burning the weeds, which causes air pollution and runs the risk of starting forest fires.

Philippines

The Philippines is even more land-constrained than Vietnam. There are on average only 0.05 hectares of arable land per capita, and population growth is amongst the highest in Asia at around 2% a year, putting further strain on the limited land. The country has been a long-time net importer of crops and struggles to avoid further deterioration in self-sufficiency. Therefore, optimizing agricultural production is of paramount importance.

Data on the costs of land preparation and weed control in manual systems and paraquat-based ones were extracted from the survey described above and are presented in Table 5. These show that the cost savings vary from $64/ha to $224/ha depending on the crop, and are in line with the scale of benefits obtained in Vietnam. It is not possible to compare revenue and yield data from the Philippines study as, being based on a farmer survey and not a controlled trial, there are many other variables apart from the method of weed control which can influence yield.

Table 5. Comparative land preparation and weed control costs for paraquat users and non-users in the Philippines: $/ha.

	Cabbage		Egglant		Potato		Chinese cabbage		Sugar cane		Yellow corn
	User	Non-user	User	Non-user	User	Non-user	User	Non-user	User	Non-user	User/ Non-user difference
Cost land preparation	99	197	48	113	131	320	29	47	79	197	–19
Cost of weeding	34	84	23	46	23	67	24	131	382	511	–23
Paraquat cost	53		22		39		26		20		+19
Spraying cost	18		3		23		3		4		+2
Net cost saving	77		64		171		96		224		21
Farmer income	9092	9565	2900	1385	6651	3551	574	357	2757	1855	na na

Table 6. Costs and revenues of traditional and no-till rice and wheat production in Sichuan, China.

		$/ha				
Crop	Regime	Material costs	Labour costs	Total costs	Revenue	Income
Rice	No-till	295	378	673	1324	651
	Traditional	390	449	839	1253	415
	Difference	–95	–71	–165	71	236
	Difference %	–24.2%	–15.8%	–19.7%	5.7%	57.0%
Wheat	No-till	404	222	626	992	365
	Traditional	513	253	765	929	163
	Difference	–109	–31	–139	63	202
	Difference %	–21.2%	–12.1%	–18.2%	6.7%	123.6%
Total	No-till	699	600	1299	2316	1016
	Traditional	902	702	1604	2182	578
	Difference	–203	–102	–305	133	438
	Difference %	–22.5%	–14.5%	–19.0%	6.1%	75.8%

Source: Yonglu Tang, *et al.* (2004) http://www.cropscience.org.au/icsc2004/poster/1/2/1320_tangaa.htm.

Assuming, conservatively, that paraquat has on average a 20% market share for these crops gives the total farmer benefit attributable to paraquat of around $30m. The details are given in the summary Table 7.

China

No-till rice-wheat and rice-oilseed rape rotation in Sichuan

The practice of rotating paddy rice with wheat and with oilseed rape in the Leshan area of Sichuan is common and no-till is used on 85% of the area amounting to around 335,000 ha. A long term study conducted in this area in the 1990s established that yield benefits of 8%, 4% and 3.8–7.1% compared to traditional practice were obtained for wheat, rice and oilseed rape respectively. These translated into the increases in revenues, as shown in Table 6. There were also reductions in labour and material costs resulting on overall increases in farmer incomes of $440/ha. Scaling these up over the whole area gives a total farmer income benefit of $150m, as shown in Table 7.

Vegetables/Guandong province

Whilst there are no data, there is considerable anecdotal evidence that in the case of multi-cropped vegetables grown in Guandong province the time-saving element from using paraquat to prepare the land and control weeds allows planting to be brought forward by 10 days. Given the crop cycle for these vegetables is only 80 days the cumulative effect of these savings is to allow an extra one, or in some cases, 2 crops to be grown per year. As these crops could not be grown without the use of paraquat it is legitimate to attribute all of their value to paraquat use. Given from the Philippines survey the farmer income from a typical vegetable crop can be well over $1000/ha, even as much as $10,000/ha (Table 5), the value of an extra vegetable crop grown on 400,000 ha can conservatively be estimated at $400m.

It is estimated that there are 12–24 million paraquat users in China. Scaled up over all of these it is quite conceivable that the overall benefits are of the order of several $ billion.

Table 7. Summary of economic benefits from paraquat use.

Country*/ comparison	Crop	Area on which paraquat used: ha	Per ha benefit from PQT: Yield benefit: tonnes/ha (%)	Per ha benefit from PQT: Cost difference: $/ha	Per ha benefit from PQT: Farmer income benefit: $/ha	Total farmer income benefit: $m
Vietnam (PQT vs Gly)	Maize	100,000	+ 0.1 – 1.1 (+4 – 39%)	+120	+ 80-250	8–25
Vietnam	Tea	na	+0.45 (+12%)	+43	+350	na
Philippines	Maize	280,000	Na	–21	+21	5
Philippines	Sugar cane	100,000	Na	–224	+224	24
Philippines	Cabbage	1,800	Na	–77	+77	<1
Philippines	Chinese cabbage	1,800	Na	–96	+96	<1
Philippines	Eggplant	5,000	Na	–64	+64	<1
Philippines	Potato	2,600	Na	–171	+171	<1
China	Vegetables	400,000 has in Guandong	1 extra crop a year	na	+1,000 (est.)	400
China	Rice-wheat rotations	335,000 has in Leishan	+0.4 (+4-8%)	–305	+440	150
Range/Sub-total		~1,200,000 has	+4% - 39%	-305 - +120	+ 21 – +440 (exc. Chinese veg)	~$600

* Philippines based on partial budget analysis which looks only at weed control and land preparation cost savings; 20% market penetration assumed.

Environmental benefits data from China

Chinese studies also provide some soil erosion data, and the percentage reductions achieved are in line with the results obtained from Vietnam. In no-till citrus in Zheijian province (Shui Jian-guo *et al.* 2004), soil erosion was reduced from 1.7 tonnes/ha and 1.0 tonne/ha in the cases of conventional tillage and glyphosate use to 0.8 tonnes/ha with paraquat. In the Yangtze River highlands, no-till reduced soil loss by up to 85% on moderate slopes and up to 50% on steeper slopes

Summary and Discussion

Table 7 summarises the economic benefits from the three countries examined in this paper.

All the studies presented above provide strong evidence that the use of paraquat contributes to significant increases in farmer income, commonly in the range $20–400/ha.

These increases can derive in roughly equal measure from the increased yields obtained, and the cost savings from reduced labour requirements for land preparation and weed control.

The increased yields can derive from a combination of factors, some of which stem from paraquat's unique properties. Figure 1 relates paraquat's benefits to the yield increases achieved and provides ranges for the different factors

In future it is likely paraquat's benefits will become even more important:

- Global warming will increase precipitation and extreme events such as floods, which will exacerbate the problems of soil erosion.

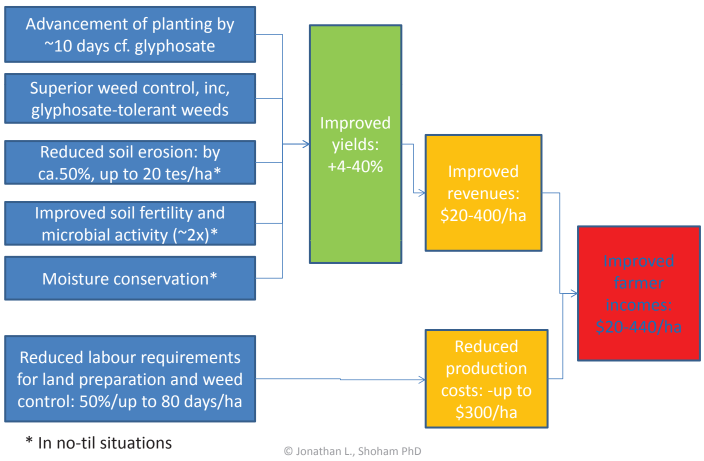

Figure 1. Relating the properties of paraquat to the economic benefits at farmer level.

- Continued high and increasing levels of glyphosate use, especially with the increasing adoption of glyphosate-tolerant GM crops, will provide the basis for the continued spread of glyphosate tolerant weeds. With its unique mode of action paraquat will be an important tool in the armoury for combating weed resistance, especially in no-till situations. No new herbicide mode of action has been introduced since 1991, so it is vital to maintain access to those which already exist in order to address weed resistance to herbicides.
- As the process of migration from the countryside to the cities continues, GDP per capita in emerging markets grows and rural labour becomes more scarce, labour costs

and with them the cost of land preparation and hand weeding will increase, further improving the cost-benefit of paraquat use.

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