Research Review

Maleic Hydrazide in potato volunteer control

Ref: R275

August 2006

Denis Buckley: *TAG*

Harry Duncan: *Univ. of Glasgow*

Eric Anderson: *Scottish Agronomy*

2006

Additional copies of this report and a list of other publications can be obtained from:

Publications
British Potato Council
4300 Nash Court
John Smith Drive
Oxford Business Park South
Oxford
OX4 2RT

Tel: 01865 782222
Fax: 01865 782283
e-mail: publications@potato.org.uk

Most of our reports, and lists of publications, are also available at *www.potato.org.uk*

CONTENTS

TABLES

INDUSTRY SUMMARY

Maleic hydrazide (MH) is a molecule that dates from the late 1940's. It has been available in the US since that time, but only appeared in the UK in the mid 1980's. The effect of MH is to inhibit cell division rather than cell expansion.

MH has 'Annex 1' listing and an MRL (of 50 mg/kg), so its efficacy and safety have been thoroughly examined at a European level. Relative to most other agrochemicals, it has an excellent environmental profile.

MH can be a valuable part of a potato volunteer control programme. When applied correctly under optimum conditions, it can be expected to give 75% or more control of volunteer potatoes in the following crop. When applied under sub-optimum conditions, control may be less, and in some circumstances there may be no significant volunteer control at all.

Most MH application is directed at processing crops with the dual function of controlling volunteers and aiding sprout suppression in store. When used correctly, growers can have every confidence it will have no impact on dry matter (specific gravity), fry colour or other processing quality characteristics.

MH should be seen as part of a programme to control volunteers. In an ideal world, other major elements in that programme would include:

- Leaving as few potatoes as possible behind in the field at harvest, which relates not just to harvesting, but seedbed preparation too.
- Not ploughing for two winters after potatoes, thereby allowing winter weather and vermin to reduce volunteer numbers.
- Establishing a winter cereal or other competitive winter crop as soon as possible after potato harvest.
- Using glyphosate, preferably post-cereal harvest at a sufficient rate to kill all emerged volunteers. Glyphosate cannot kill volunteers which have not emerged at the time of application!
- Using appropriate herbicides and perhaps inter-row cultivation elsewhere in the rotation.

In addition, the use of 1,3-dichloropropene (Telone II) for the knockdown of high PCN populations, may also give a useful reduction in volunteer numbers.

MH appears to be much less rainfast than any other agrochemical used in potato production. The uptake of MH into the leaf is relatively slow and it is therefore prone to wash-off, especially in the first 12 hours after application. A period of 24 hours without rain or irrigation is highly desirable.

High temperature and low humidity conditions can cause MH to crystallise on the leaf surface and not be absorbed into the plant. In the US, at least one product label recommends application at temperatures below 26^{o}C if the daytime maximum is expected to exceed 29^{o}C.

Because MH is not translocated evenly to all tubers, neither sprout control nor volunteer control is complete following its use. Although one could argue that because translocation of MH to smaller tubers is less than to larger ones, its effects on volunteer control should be poor. However, in practice, it is larger tubers left behind in fields which give rise to the most vigorous and aggressive volunteers, and these are the very ones which take up the most MH.

Maximum uptake into tubers probably takes place within a week at most of application, but it is likely that further redistribution between tubers probably occurs within the period up to five weeks after application. Acceptable activity probably occurs three weeks after application.

Application within three weeks of planned desiccation should be avoided, not only because of reduced overall activity, but because of the possibility, albeit extremely remote, of having a residue in a low yielding crop which exceeds the MRL.

Excessively early application, which is most unlikely in commercial practice, can cause severe yield reductions and be associated with an increase in malformed tubers and coarse skins. Anecdotally, early application following late planting, where the crop is somewhat immature at the time of application, has occasionally caused growth cracking in crops grown in GB.

When applied when the crop is sufficiently mature, there will no yield reduction and no alteration in tuber size distribution. But when applied before the crop is sufficiently mature, there may be reductions in the large ware (baker) fraction also reducing total yield. Where crops are planted late, from say the second week of May on, and need to be desiccated early, say early-mid September, it may be difficult to completely combine both absence of yield effects with optimum activity.

Unlike in the USA, the current UK product labels do not give enough weight to the need to ensure the crop is sufficiently mature before MH application is made, both in terms of flowering and tuber size. US product labels typically do not recommend application until 2-3 weeks past full bloom (flowering) and when the smallest tubers required to reach marketable size are 38-50mm in diameter, depending on variety and location where grown.

Activity of MH depends on it being ‘free’ within cells. Over time, increasing amounts of MH can become bound to cell contents, reducing its activity both as sprout suppressant and volunteer control.

THE DEVELOPMENT OF MALEIC HYDRAZIDE (MH) IN POTATO PRODUCTION SYSTEMS

The plant growth regulation caused by maleic hydrazide (MH) was first described in the journal *Science* in 1949 (Anon. 2003). It inhibits cell division, but not cell extension of existing cells. It differs from other sprout suppressants in that it is applied as a foliar spray rather than a storage treatment, and it is this which gives it its dual role of both volunteer control and sprout suppressant.

By 1951 experiments with MH in potatoes and other crops had already been published. For example see Kennedy and Smith 1951.

By the mid-1960's MH was well established in the US potato industry as a sprout suppressant, especially in the processing industry (Talburt and Smith 1967).

In the 1970's, in the UK, MH was restricted to uses such as suppression of grass growth, sucker growth on certain trees and the suppression of onion sprouts in store (Anon. 1977), although by then the basic requirements for successful activity in potatoes had been understood and documented. For example, Burton (1978) described MH as being applied at 2.5 kg/ha a.i. 3-5 weeks before death or destruction of foliage. He noted the possibility of reduction in yield and misshapen tubers with excessively early application and it being ineffective when applied too late. Also, 'successful use of maleic hydrazide requires long periods of predictable weather' implying the need for a good spell of dry weather after application to ensure uptake into the foliage.

In 1984, the commercial product Fazor gained 'limited commercial clearance' under the then Pesticide Safety Precautions Scheme for the use of MH on 15,000 ha of potatoes (ADAS internal communication). It was launched with the dual role of both sprout suppressant and reduction of volunteers.

Since that time, MH has been used to fulfil the same dual role in potato production systems. Anecdotally, it would appear that the main reason for its use is the suppression of sprouting in the long-term storage of chipping and crisping crops. This has been driven by the market demand for fry colour at the time of sale, which in turn means relatively high storage temperatures and therefore the need for excellent sprout suppression.

Growers frequently cite the need for suppressing the build-up of PCN as a reason for potato volunteer control but there appears to be precious little data on the subject. However, Dewar *et al* (2000) working with genetically modified sugar beet, were able to demonstrate reduced multiplication of PCN at three out of four sites where artificially planted volunteers were sprayed a range of herbicides, including glyphosate, and those conventionally used in sugar beet, with or without clopyralid.

TABLE 1. REDUCED MULTIPLICATION OF PCN THROUGH POTATO VOLUNTEER CONTROL (Dewar *et al* 2000).

	Littleport 1998		Ramsey 1998		Southery 1999		Ramsey 1999	
Treatment	**Pi**	**Pf**	**Pi**	**Pf**	**Pi**	**Pf**	**Pi**	**Pf**
Conventional	23.0	55.2	129.2	118.1	78.1	140.0	23.2	54.9
Conv. + clopy	24.7	49.4	130.7	104.9	78.3	131.0	24.1	53.6
Gly early	-	-	120.3	109.3	88.5*	56.7*	27.2	24.4*
Gly late	24.2	18.3*	119.0	105.3	77.4	50.2*	30.1	17.7*
Gly early + late	23.9	33.8*	-	-	83.4	60.6*	23.7	14.6*
SED	3.64	10.57	8.91	7.01	3.71	12.03	3.93	4.75

* significantly different from conventional
Pi = initial PCN population, Pi = final PCN population (eggs/gm of soil).

From the relatively even distribution of initial PCN populations (Pi) these were clearly old, well established infestations. Except at Ramsey in 1998, where the volunteers were largely dead by mid-July, aided and abetted by an attack of blight, all glyphosate treatments significantly reduced PCN populations compared with the conventional herbicide treatments. In some ways these results are a little disappointing, in that one might expect the glyphosate-treated volunteers to act more as a trap crop in reducing PCN populations than they did. The subject of the role of volunteers in maintaining PCN populations is one which requires further research.

CURRENT PATTERN OF USE IN POTATOES

Official Pesticide Usage Surveys are carried out on behalf of the Pesticides Safety Directorate (PSD) by the Central Science Laboratory (CSL). Potatoes are included in the survey every other year and the data is available online (Internet ref. 4). The data for MH since 1990 are as follows:

TABLE 2. USAGE OF MH IN GB ON POTATOES SINCE 1990.

Year	Area treated (ha's)
1990	4,379
1992	4,171
1994	17,690
1996	10,185
1998	9,352
2000	22,288
2002	27,443
2004	15,150

These data appear to be subject to some 'noise' in that it seems unlikely the area treated fell so dramatically between 2002 and 2004. One is inclined to think the area treated is approximately an average of the 2000-2004 figures, which would be say 21,500 ha's. With the current GB potato acreage being circa 125,000, that would mean 17.2% of the GB acreage treated with MH. The official PRC residue data (see section 6.6) shows 99 samples out of a total of 562 over the same period containing residues of MH, or 17.6%. These numbers appear to correspond reasonably well.

In the UK, products containing MH Approved for application to potatoes are formulated as water soluble granules containing 60% maleic hydrazide as the potassium salt.

There are currently two agrochemical companies selling MH products in GB. Dow AgroSciences market Fazor, and this is manufactured by Chemtura Corporation. All the other products are manufactured by Drexel Chemical Company and include Source II (Chiltern Farm Chemicals), Rouge (Nufarm) and Malahide (Cleanacres). Chiltern Farm Chemicals are responsible for the marketing and technical support of both Rouge and Malahide.

There are also specific off-label approvals (SOLA's) for the use of some MH products in carrots and parsnips.

Other MH-containing products are available for non-crop use such as growth retardation in amenity grass and hedges.

MH is mainly used in processing crops and there is little doubt that the correct use of MH will have no material effect on processing quality. For example, Kennedy and Smith (1953) were unable to measure any significant differences in specific gravity or fry quality. Small differences in reducing sugar content between MH treated and untreated potatoes were noted by Paterson *et al* (1952) but there appears to be no experiments demonstrating significant changes in processing quality when used at similar rates and timings to those on the current labels. Timm *et al* (1959) measured no significant differences in yield or specific gravity in California from the use of MH. Nor did they record differences in fry quality, mealiness or taste as a result of using MH. One observation they did make was sprout inhibition was least variable with the application three weeks prior to harvest rather than two and this would be very applicable to volunteer control. Franklin and Thompson (1953) recorded no significant differences in yields, specific gravities, cooked colour ratings or flavour scores form MH treated potatoes at harvest. Some differences in specific gravity were recorded after storage for 6 months, but the comparison was with potatoes without any sprout suppressant treatment. Yada *et al* (1991) working in Ontario, found no apparent effect on yield, sugar content or fry colour from the use of MH.

APPROVAL STATUS OF MH

MH was granted "Annex 1" listing on 1 January 2004 (Internet ref. 2). Annex 1 itself is an annex to Council Directive 91/414/EC, which concerns itself with rules governing the marketing of plant protection products. Inclusion of an active ingredient in Annex 1 means that the effects on human health and the environment have been assessed, and that approved products containing that active ingredient can be marketed. Annex 1 listing for MH automatically expires on 31 December 2013.

In 2005, a maximum residue level (MRL) for MH was fixed within the EU at 50 mg/kg (Internet ref. 3). Up until 2005 there was no MRL in the UK. The MRL in the USA is also 50 mg/kg. After ingestion, the main route of elimination appears to be in urine (Internet ref. 11).

MH is formulated only as the potassium salt. Some of the original products (and research) relating to MH used diethanolamine salts, but there were safety concerns regarding these formulations, and they were replaced in the early 1980's, before the introduction of MH to the UK, by the potassium salt.

Relative to most agrochemicals, MH has an excellent environmental profile. It is not toxic to bees or fish, its half life in the soil is approximately 11 hours, and it undergoes rapid photochemical degradation in water (Anon. 2003 and Internet ref. 5).

The acceptable daily intake (ADI) is the amount of a substance which can be ingested every day of an individual's entire lifetime, in the practical certainty, on the basis of all known facts, that no harm will result. The ADI is expressed as milligrams (mg) of chemical per kg body weight of the consumer. The ADI for MH is 0.25 mg/kg of body weight per day. For a person weighing 70 kg, the ADI is therefore 70 x 0.25 = 17.5 mg. This is equivalent to eating 0.76 kg/day of potatoes every day for life with the highest ever residue of MH recorded in PRC surveys (23 mg/kg. See section Official PRC data published by PSD).

The ADI itself is derived from the most appropriate No Observed Adverse Effect Level (NOAEL). The NOAEL is the highest exposure level in a toxicity study at which there are no statistically significant and/or biologically significant increases in the frequency of adverse effects between the group of animals exposed to the test substance and its respective control group. The ADI is set at 1% of the NOAEL.

REVIEW OF AVAILABLE EXPERIMENTAL DATA AND ANECDOTAL EVIDENCE ON POTATO VOLUNTEER CONTROL

Much of the data relating to the use of MH relates to sprout control rather than volunteer control. However, for obvious reasons the two are intimately related, and good sprout control can also be interpreted as good volunteer control, and *vice versa.*

Early GB work

The first published work on volunteer control using MH in this country is probably that of Peddie *et al* (1986). In experiments conducted in farm crops, MH was applied by either tractor mounted sprayer or aerial application. With all the tractor applications, the mean control of volunteers, when assessed the following June/July, was above 70%. At the two sites where MH was applied by air as well as by tractor mounted sprayer, the tractor mounted sprayer gave the better result. There are no statistics attached to these results and therefore they should be regarded as observation studies.

TABLE 3. CONTROL OF VOLUNTEERS IN COMMERCIAL POTATO CROPS. (Peddie *et al* 1986).

	% control of volunteers at each site			
Treatment	**1**	**2**	**2**	**4**
Control (vols/m^2)	(18.6)	(97.2)	(6.4)	(7.9)
MH ground	82.8	91.4	70.3	97.5
MH air	69.4	80.9	-	-
Location	Cambs.	Lincs.	Notts.	Derbys.
Soil type	peaty loam	silt loam	sandy loam	sandy loam
Variety	M. Piper	Cara	Record	Desire
Application date	Sept 3	Aug 30	Aug 28	Sept 18
Desiccation date	Oct 1	Sept 28	Sept 20	Oct 29
Following crop	Sugar beet	W. Wheat	W. wheat	B. sprouts

Considering the water volume used was 300-400 l/ha by ground application, but only 20-30 l/ha by air, the results from the aerial treatment are remarkably good and do beg the question as to why such high water volumes are normally recommended with MH (350 to 500 l/ha in the case of Fazor and 300 to 600 for Source II). After all, combining the weather window with the time window for application can often lead to quite a narrow interval in which MH can be correctly applied, and reducing water volume certainly means more hectares sprayed in a day at the correct time. This is worthy of further investigation.

In the same paper, the results of replicated experiments on Cara and P. Squire are reported, where MH was applied on several dates before desiccation. Following storage, treated tubers were planted in pots in a glasshouse and assessed after several months for sprouting. For illustration, just the results for P. Squire are shown here.

TABLE 4. PENTLAND SQUIRE. EFFECT OF MH ON GROWTH CHARACTERISTICS AND RESIDUES (Peddie *et al* 1986).

Treatment	MH application, weeks before desiccation 5	4	3	2
Ware				
% reduction in sprout wt.	92.6	94.3	88.4	82.4
MH residue at harvest (mg/kg)	18.3	5.8	10.3	12.4
Seed				
% reduction in sprout wt.	86.8	73.7	64.0	84.2

Residues were not measured in the seed fraction. There was a tendency for there to be a greater reduction in sprout weight from the earlier application timings and also for a greater reduction in the ware rather than the seed fraction. This has been the pattern of results from many other experiments.

Inconsistent sprout control in early US research

Sawyer and Dallyn (1958) working in New York State, noted inconsistent sprout control in commercial crops. In order to try and tie down the best timing in terms of crop growth, they applied MH at two rates (equivalent to 5.6 or 9.6 kg/ha of Fazor or Source) at five different timings in 1953. They found that the lower rate of application gave excellent control of sprouting when applied at blossom fall (end of flowering) or shortly thereafter, but when applied later, the higher rate was necessary for sprout control in the variety Katahdin (see table below). There was no effect on quality parameters or yield, regardless of rate and timing. Also, residue analysis corresponded well with sprouting.

TABLE 5. EFFECT OF RATE AND TIMING OF MH IN NY STATE IN 1953 (Sawyer and Dallyn 1958).

Dose lbs/acre	Timing	Yield US No. 1*	Specific gravity	Sprouts gms/kg tuber	MH residue mg/kg
3	early bloom	660	1.0735	11	7.9
3	full bloom	582	1.0720	2	12.6
3	blossom fall	565	1.0740	7	18.2
3	2 wks. after blossom fall	672	1.0745	7	13.0
3	4 wks. after blossom fall	638	1.0727	29	4.2
5	early bloom	655	1.0717	17	5.5
5	full bloom	601	1.0725	8	11.8
5	blossom fall	624	1.0722	0	18.7
5	2 wks. after blossom fall	652	1.0715	1	9.9
5	4 wks. after blossom fall	686	1.0745	4	5.9
control		618	1.0730	33	-

* Yield US No. 1. For practical purposes this can be regarded as graded ware yield.
N.B. No statistics were provided with these data.

There certainly seems to be some inconsistency in the results, in that the first timing at 'early bloom' resulted in relatively poor sprout control and low residues whereas one would have expected the opposite, given the amount of time available for translocation of MH to the tubers. This inconsistency has been a feature of much of the research work and the practical experience of growers. However, in commercial practice now, an understanding of the conditions necessary for good uptake of MH has probably reduced the risk of that inconsistency interfering with expected performance.

In 1954, for the second year in a row, neither dosage nor time of application had any effect yield. Also, application more than two weeks after blossom fall failed to give good sprout control.

In 1955, early applications of MH did result in severely reduced yields. The two timings which combined good sprout control with unaffected yields were 'blossom fall' and two weeks after blossom fall.

TABLE 6. EFFECT OF TIMING OF MH IN 1955 (Sawyer and Dallyn 1958).

Timing	Yield US No. 1*	Specific gravity	Sprouts gms/kg tuber	MH residue mg/kg
early bloom	245	1.0745	1.98	22.0
full bloom	422	1.0793	0.17	27.8
blossom fall	561	1.0803	0.33	30.3
2 wks after blossom fall	570	1.0799	1.59	14.6
4 wks. after blossom fall	566	1.0798	4.84	7.0
Control	568	1.0817	14.29	0.2

This published research appears to have been important in understanding the correct timing for MH application in the field.

Inconsistent volunteer control

Thomas and Smith (1983) reported very variable effects from applications of MH. In a two year experiment in Washington State using Russet Burbank, MH was highly effective in the first year but not in the second. In Year 1, average volunteer numbers across a range of cultivation treatments were reduced from 82.2 per plot in the untreated to 9.6 per plot by MH treatment two weeks after full bloom, whereas in Year 2 the reduction was from 148.5 per plot in the untreated to 91.5 in the MH treated, which was a relatively disappointing result.

Uptake of MH into plants can be surprising rapid

Franklin and Lougheed (1964) working in Ontario, sprayed two varieties of potato with MH three weeks after full bloom and removed haulm from representative samples at intervals ranging from hours to 22 days after application. The potatoes were then harvested, and following storage for six months, were assessed for various parameters related to sprouting. The authors reported that sprouting was satisfactorily inhibited following MH absorption over a 24 hour except for occasional tubers with long sprouts. Such tubers occurred at random and came from plants where sprouting in the other tubers was suppressed.

TABLE 7. ABSORPTION PERIOD AND SPROUTING IN CV SEBAGO (Franklin and Lougheed 1964).

Absorption period	Sprout length (ins)	Sprout wt. %	Tubers sprouted %
0	11.55	9.18	88.6
2	14.38	9.36	77.5
4	13.66	8.99	92.7
8	10.30	5.59	92.9
24	0.25**	0.29**	83.3
48	0.08**	0.10**	4.4**
LSD (1%)	5.91	7.58	37.83

Residue levels in tubers from non-defoliated plants rose for only seven days after MH treatment, reaching a maximum of 36 mg/kg.

McKenzie (1989), working at Glasgow University, measured stable residues of MH from one week after treatment.

TABLE 8. TUBER RESIDUES OF MH RELATED TO TIME AFTER APPLICATION (McKenzie 1989).

Weeks after application	MH residue mg/kg
1	19.5
2	20.7
3	17.8
4	19.1

The data from both these experiments are at variants with other research findings and field experience, which suggests that at least three weeks is required for sufficient uptake and translocation for reliable sprout control.

Paterson *et al* (1951) working in Michigan, treated potatoes with differing amounts of MH on a range of dates from mid-July to early September 1950. Only two days after the last treatment date, haulm was removed and tubers were harvested four days later. In the spring of 1951, the authors planted in the field tubers from MH treated plots showing no sprouting in store, and these showed "no evidence of growth activity". This is probably the first report of potential volunteer control using MH. Again there was a surprising result in that defoliation so soon after application still resulted in some sprout inhibition, but only at the highest rate tested. This experiment was the first to indicate a rate/timing interaction in that the effect of late spraying could be at least partly overcome by a higher rate of active ingredient applied.

TABLE 9. SPROUTING IN CV PONTIAC STORED AT 55^{0}F (Paterson *et al* 1951).

Treatment date	MH concentration in the spray (ppm)*	Grams of sprouts per 10 tubers
15 July	500	110.5
	1000	50.0
	2500	3.0
2 August	500	40.0
	1000	3.5
	2500	0.0
11 August	500	68.0
	1000	24.5
	2500	26.0
2 September	500	156.5
	1000	133.0
	2500	75.5
Control		115.0
LSD (5%)		33.8

*Application of MH is expressed in terms of concentration and it is not possible to calculate kg/ha a.i. applied.

Large tubers contain more MH and exhibit better sprout and volunteer control

McKenzie (1989), working in Glasgow, noted best sprout control in larger fractions.

TABLE 10. CONTROL OF SPROUTING ACCORDING TO TUBER SIZE (McKenzie 1989).

	% Sprouted tubers after storage (5 months @ 8^{0}C)		
Mean MH residue in sample (mg/kg)	**< 30 mm**	**30-45 mm**	**> 45 mm**
0 (control)	100	100	100
4.7	46.5	41.8	17.4
10.7	45.5	27.3	7.4

At higher average residue levels, the improvement in sprout control in the smaller fractions, which are the ones most likely to be volunteers, was less than in the larger fractions. In theory this is a potentially disappointing result from the point of view of volunteer control, because the majority of tubers left in the ground are small rather than large. However, in practice, foliage arising from small potatoes is less vigorous and easier to kill by other means.

Reports of tuber damage

Instances of tuber damage caused by MH appear in the literature and are reported anecdotally. All seem to be associated with excessively early application in terms of crop maturity, and/or, in the case of early experiments, with high rates of application. Denisen (1953) in Iowa reported many misshapen and small tubers, some with sloughed skins, as well as russeting of the skin with secondary growths and growth cracks. The descriptions in the literature of severe crop effects appear not dissimilar to those caused by sulfonyl urea herbicides used in cereals such as metsulfuron-methyl (Ally).

Also in terms of crop effects, Davis and Groskopp (1981) noted that treatment with MH early in the growing season caused substantial yield reductions ranging from 26 to 48% and these were accompanied by "an abundance of malformed tubers". Even later applications in the late-July to mid-August period caused small but significant yield reductions of 4.9-5.7%, although in this experiment, application in late July or early August resulted in reduction of undersized tubers, although as a percentage of total weight, these differences were small.

TABLE 11. SMALL REDUCTIONS IN UNDERSIZED TUBERS FROM MH APPLICATION (Davis and Groskopp 1981).

	Yield (% of total wt.)					
Date of application	**Malformed**	**Undersize**	**4-6 oz**	**6-10 oz**	**10-13 oz**	**>13oz**
untreated	9.7	8.1a	24.8a	34.6	11.3	10.5
23 July	11.3	6.6b	28.3b	33.4	10.4	9.1
2 August	10.0	6.6b	26.0ab	24.7	10.7	10.8
13 August	10.1	8.0a	26.2ab	32.9	11.4	10.2

Means with different letters denote significant differences (P = 0.05)

A reduction in small tubers (in this case under 48 mm) was also reported by Kennedy and Smith (1951), from an application of MH on 4 September. It should be noted that this experiment was not planted until June 12 and harvested on October 18, 1950. It would appear that reductions in small tubers are an occasional inconsistent response to the use of MH. When they occur they are to be welcomed, because they will surely be accompanied by a reduction in volunteers, with fewer small tubers left behind in the field.

Humidity after application and formulation has an effect on uptake

Smith *et al* (1959) working with tomatoes, were able to demonstrate that low humidity conditions reduces uptake. They state that the absorption rate at 100% RH is two to three times that at 75% and three to five times that at 50%. Although different formulations affected uptake too, there was still an effect of humidity.

TABLE 12. EFFECT OF HUMIDITY ON DIFFERENT MH FORMULATIONS (Smith *et al* 1959).

	Absorption in 48 hours (%)	
Formulation	**75% RH**	**100% RH**
Potassium salt	20	40
Potassium salt + sorbitol	35	65
Diethanolamine salt	40	80

The authors comment that many other additives such as urea, ammonium salts oils and stickers have been evaluated in diethanolamine salt formulations, but none significantly increased the absorption rate. Nevertheless, it is the potassium salt formulations which now dominate the market and our understanding of additives has improved markedly since this work was carried out. Anecdotally, we still hear of instances of poor activity when MH is applied under hot, dry conditions. Experiments to investigate the effect of adjuvants in helping to overcome environmental variables beyond the control of the potato grower would be worthwhile.

High temperatures often go hand in hand with low humidity. In the US, at least one product label recommends application at temperatures below 26^{o}C if the daytime maximum is expected to exceed 29^{o}C.

MH can reduce or increase numbers of malformed tubers depending on time of application

Weis et al (1980) working in Wisconsin, found that applications of MH to Russet Burbank could reduce numbers of malformed tubers. Excessively early application (early to mid June following planting in late April) could lead to increase in malformed tubers as well as yield reductions. They presented results which were the average of three years of experiments and these are shown below.

TABLE 13. EFFECT OF MH TIMING ON YIELD AND OUTGRADE (Weis *et al* 1980).

MH application timing	Total yield (t/ha)	Outgrades as % total yield *	Specific gravity
early June	28.64 b	71.9 a	1.076 c
mid-June	28.41 b	45.5 b	1.080 b
late-June	51.15 a	18.5 cd	1.086 a
early July	51.74 a	14.6 d	1.088 a
mid-July	50.21 a	13.8 d	1.088 a
late July	53.28 a	16.2 d	1.088 a
early August	51.07 a	17.8 d	1.088 a
mid-August	54.13 a	23.0 cd	1.087 a
Control	52.19 a	30.1 c	1.087 a

*includes malformed, greens, damaged and diseased tubers
Letters in common indicate no significant difference at the 5% level.

BPC Research findings

PMB (now BPC) research with MH at Sutton Bridge took place over two years (Anon. 1987 and 1988). In 1985 an observation study was undertaken where yield at harvest, and sprouting and weight loss following storage were measured. Relatively late applications of MH in terms of calendar date still resulted in reasonable sprout control. Residues were very variable from crop to crop, again indicating inconsistent uptake into plants following application. In the following year there were no differences in the mean total or ware yield from five crops treated. MH did not suppress sprouting as completely as chlorpropham, but was better than the untreated control. In this second year experiment, volunteers in the following crop were also recorded.

TABLE 14. VOLUNTEERS IN MAY/JUNE FOLLOWING CROP AFTER MH TREATMENT (Anon. 1998). Measurements taken in ten random 3m diameter circles.

Site	Variety	Following crop	MH treated	Untreated
1	Record	W. Wheat	1	17
1	M. Piper	W. Wheat	6	14
2	Record	W. Wheat	0	19
3	M. Piper	W. Wheat	10	12
4	P. Dell	carrots	14	105
5	P. Dell	onions	82	162

It would appear that the lack of competition afforded by carrots and onions encouraged volunteer numbers. There are clearly inconsistent responses to MH treatment in terms of volunteer control. At site 3 in particular, there was little if any difference between treated and untreated. This was not due to insufficient interval between application and desiccation (29 days). Residues were not recorded in this experiment.

Other GB research

Hinchcliff *et al* (1993) demonstrated mean control of volunteers of 74% at three sites following treatment with MH, with arrange of 62 to 85% control. They commented that one of the treated crops was suffering severe aphid attack and drought stress at the time of MH application and yet good control of volunteers was still achieved.

Ogilvy *et al* (1989) summarised a series of experiments at three ADAS experimental farms over several years. The data from ADAS Terrington is discussed in more detail below. At ADAS Arthur Rickwood, MH was applied to Maris Piper at 20% crop senescence two weeks prior to desiccation in 1984. In 1985, 1986 and 1987, it was applied three weeks prior to desiccation to Kingston. The effect of volunteers was assessed both in the first and second wheats after potatoes.

TABLE 15. EFFECTS OF MH ON VOLUNTEERS /M^2 IN 1ST AND 2ND WHEATS AT ADAS ARTHUR RICKWOOD (Ogilvy *et al* 1989).

	1985		1986		1987		1988	
Treatment	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Untreated	3.5	3.1	4.2	2.2	2.8	0.4	1.1	1.8
MH	0.8	2.0	1.5	1.9	0.7	0.1	0.3	1.5
SED	0.72	0.45	1.26	0.48	0.77	0.15	0.28	0.43

Treatment of the mother crop resulted in a consistent reduction of the groundkeeper population in the following cereal crop of between 64 and 77%, despite the relatively early application timing, especially in 1984. The effect on residual populations in the second wheat was less apparent, which would indicate the need to keep attacking potato volunteers wherever possible in the rotation.

Research at ADAS Terrington

Probably the most comprehensive independent research on MH in the UK was carried out at ADAS Terrington in the late 1980's by Rogers-Lewis. Some of the data was reported by Ogilvy *et al* (5.12.2 above) and Heath *et al* (1993) but most appears only in internal ADAS experiment reports and remains largely unpublished. For that reason, the more relevant data is presented in some detail below. In 1987, Romano, planted relatively late on 4 May was treated with MH on a series of dates. The crop was desiccated on 9 September and by then, was approximately 60% senesced. Yield, tuber number and tuber quality were assessed.

TABLE 16. EFFECT OF MH ON TOTAL AND LARGE WARE YIELDS AT ADAS TERRINGTON 1987 (unpublished).

	Yield t/ha	
Timing of MH application	**Total**	**65-85mm**
control	51.4	13.8
30 June	44.6	9.2
10 July	44.5	6.6
31 July	48.8	14.3
7 Aug	50.3	10.7
17 Aug	53.1	16.6
19 Aug	49.8	16.6
SE per plot	±2.95	±2.98

Both total yield and yield of large tubers (bakers) was significantly reduced from MH application on 30 June and 10 July. Differences in total tuber number were not statistically significant (data not shown). It was noted that MH application on 30 June produced severe netting and partly white skin, along with a higher yield of outgrades due to dolls. Also, MH application on 30 June and 10 July affected the foliage and after about a fortnight it became paler, it subsequently hardened and leaf roll developed. However, these symptoms did not affect senescence.

Harvested tubers were replanted in 1988 and grown as a normal ware crop. Volunteer emergence, yield and tuber number were assessed. The most pertinent results from that experiment are shown in the table below.

TABLE 17. VOLUNTEER CONTROL IN 1988 FROM 1987 MH APPLICATION AT ADAS TERRINGTON (unpublished).

	Emerged plants % on 6 September 1988 from tubers:		**Total yield t/ha in 1988 from tubers:**		**Total tuber numbers 000's/ha in 1988 from tubers:**	
Timing of 1987 MH application	**65-75mm**	**35-45mm**	**65-75mm**	**35-45mm**	**65-75mm**	**35-45mm**
control	100	100	47.1	35.6	409	257
30 June	5.2	10.0	3.1	2.7	22	25
10 July	0.0	1.7	0.0	0.3	0	6
31 July	0.0	3.3	0.4	1.3	4	13
7 Aug	0.0	10.0	0.1	3.2	2	21
17 Aug	1.7	48.3	0.1	14.9	5	99
19 Aug	0.0	30.0	0.0	8.3	1	58

In the above table, the parameters measured are averages from tubers stored conventionally and chitted, because in the original datasets these are not materially different. Statistical analysis of the data was not carried out. By growing MH treated tubers as a conventional potato crop in 1988, the 'volunteers' were presented with ideal growing conditions which would not occur in practice. The experiment therefore provides us with valuable data as to what a 'worst case scenario' might be. Two mm of rain fell on 17 August 1987 with another 1.6 mm the following day, and it would appear the rain did have some effect on uptake, in that all the parameters of volunteer control in 1988 were worse from 17 August treatment compared with 19 August.

Fewer volunteers emerged from large tubers. The optimum overall timing for volunteer control appeared to be 10 July, a time when both total and baker yields were statistically lower than the untreated. In other words, optimising both yield and volunteer control with a relatively late planted crop like this seems to involve some degree of compromise. The interval between the last application on 19 August and desiccation on 9 September was 21 days, which is the minimum interval on the label. Volunteer control was still substantial at this timing.

In most crop rotations, volunteers derived from small tubers would face either crop competition and/or herbicide activity, both of which would be more detrimental to volunteers derived from small rather than large tubers. These results therefore probably overstate the real influence of small tubers left behind in fields following MH treatment.

In this same experiment, the volunteer tubers planted in 1988 were dug up at the end of the growing season to see how many were still sound. It was noted that some of these exhibited 'little potato disorder' and the number of tubers so formed was recorded.

TABLE 18. EFFECT OF MH TREATMENT IN 1987 ON VOLUNTEERS AT THE END OF THE 1998 GROWING SEASON AT ADAS TERRINGTON (unpublished).

Timing of 1987 MH application	% firm intact spring-planted tubers at harvest 1988	Total No. little potatoes 000's/ha formed at harvest 1988 on tubers treated in 1987 from: 65-75mm	35-45mm
control	0	0	0
30 June	44.6	3	1
10 July	44.5	50	14
31 July	48.8	0	8
7 Aug	50.3	0	8
17 Aug	53.1	6	3
19 Aug	49.8	14	6

Around 50% of tubers from 1987 MH-treated crop planted in spring 1988 remained intact in the autumn of 1988 and in theory these could survive and emerge at a later date, especially when one bears in mind the work of Dias and Duncan (1999) demonstrating how MH can become bound and inactive within cells over time (see section 6.4). Excluding 30 June and 10 July timings, which would not occur in commercial practice, there is no clear pattern as to whether the threat of 'little potatoes' formed from large or small 'volunteers' is the greater. It would not be unreasonable to assume that these 'little potatoes' would have low levels of MH, but we do not know if they would have tuber reserves to emerge the following spring.

One of the unknown questions regarding MH is whether the effect on volunteer is permanent and real, or whether a problem is simply being delayed (Keer, J, 2006, personal communication). These data from ADAS Terrington ask more questions than they answer in that regard.

The direct foliage damage from early MH application has been noted occasionally in the field (Florendyne, B, 2006, personal communication). In a BPC-funded experiment at ADAS Gleadthorpe in 1998 (Buckley D, 1998) foliage scorch to the late-maturing variety Cultra was noted following application of MH especially on 23 July but also 12 August, but there was no significant effect on either yield or tuber size distribution in this case. The crop had been planted on 28 April. It may be that effects on foliage are related to degree of foliage maturity at the time of application. If new foliage is still being formed, then it would stand to reason that MH would be preferentially translocated to it and that could result in foliage damage, albeit cosmetic.

Repeat experiments at ADAS Terrington in 1988 and 1989

The same experiment was repeated again at ADAS Terrington in a crop of Romano planted on 15 April 1988.

TABLE 19. EFFECT OF MH ON TOTAL AND LARGE WARE YIELDS AT ADAS TERRINGTON 1988 (unpublished).

	Yield t/ha	
Timing of MH application	**Total**	**65-85mm**
control	45.1	11.6
30 June	41.9	8.7
11 July	41.5	7.5
20 July	44.1	10.6
1 August	44.0	10.3
8 August	44.3	9.7
17 August	47.0	12.3
SE per plot	±2.77	±3.19

There was no statistically significant reduction in either total or baker yield from MH treatment, but as in the 1987 treated crop, both total and baker yields were lowest at the earliest two treatment dates. With the crop planted approximately three weeks earlier than in 1987, it would have been more mature at the earlier MH application timings and so any deleterious effect on yield could be expected to be smaller. As for rainfall, 3 mm fell within 24 hours of application on 30 June, 1.1 mm on 20 July and 0.8 mm on 8 August. Defoliation of this crop took place on 6 September, 20 days after the last MH application, by which time senescence averaged 88%.

Again, progeny from the 1988 treated crop was stored and replanted in spring 1999 and grown as though it was a normal ware crop. But this time, very small tubers (under 25mm) were stored and then replanted to better mimic volunteers left behind following a commercial potato crop.

TABLE 20. VOLUNTEER CONTROL IN 1989 FROM 1988 MH APPLICATION AT ADAS TERRINGTON (unpublished).

	Emerged plants % on 1 September 1989 from tubers:			**Total tuber numbers 000's/ha in 1989 from tubers:**		
Timing of 1988 MH application	**65-75mm**	**35-45mm**	**<25mm**	**65-75mm**	**35-45mm**	**<25mm**
control	100	97	100	389	236	131
30 June	33	20	67	66	33	88
11 July	27	17	77	53	32	91
20 July	0	10	67	0	22	63
1 Aug	23	23	67	87	42	76
8 Aug	3	40	83	0	62	90
17 Aug	3	60	83	21	103	111

Again, the effects of MH on large tubers were greater than those on small, which were especially poor at later timings. It would appear that MH may well be taken up into crops within a week of application, but it seems to require perhaps 4-5 weeks to become as evenly distributed as it is ever going to be within the plant. Experience at Dow would suggest that MH treatment earlier than 5 weeks before desiccation doesn't improve the evenness of MH distribution within tubers (Savage P, 2003, personal communication) and one would expect this to be carried over into volunteer control.

In the third and final year of the experiment (1989), the variety was again Romano, and as in 1987 planting was late; in this case it took place on 12 May 1989.

TABLE 21. EFFECT OF MH ON TOTAL AND LARGE WARE YIELDS AT ADAS TERRINGTON 1989 (unpublished).

	Yield t/ha	
Timing of MH application	**Total**	**65-85mm**
control	41.4	17.7
11 July	33.5	10.6
24 July	36.4	14.0
28 July	38.0	16.3
4 August	37.3	13.8
11 August	41.0	15.7
18 August	40.4	16.9
SE per plot	±2.77	±1.70

Defoliation took place on 11 September, 24 days after the last application, but unfortunately percent senescence at the time was not reported. Total yield was significantly reduced by MH application on 11 and 24 July, and the yield of bakers was significantly reduced by applications on 11 July, 24 July and 4 August. Taking an overall view of the yield data, if this were a commercial crop, one would not have wanted to apply MH before 11 August.

As in the previous two years, treated tubers were harvested and replanted as a commercial crop the following year.

TABLE 22. VOLUNTEER CONTROL IN 1990 FROM 1989 MH APPLICATION AT ADAS TERRINGTON (unpublished).

	Emerged plants in autumn 1990 % from tubers:			**Total tuber numbers 000's/ha in 1990 from tubers:**		
Timing of 1989 MH application	**65-75mm**	**35-45mm**	**<25mm**	**65-75mm**	**35-45mm**	**<25mm**
control	100	100	100	418	258	162
11 July	0	10	40	0	29	50
24 July	0	20	57	0	27	67
28 July	60	77	97	236	168	122
4 Aug	10	37	57	11	54	64
12 Aug	20	30	83	48	54	107
18 Aug	23	47	77	70	81	87

Unlike in the previous two years, the pattern of emergence and tuber number is not especially clear-cut; in particular, the poor performance of the 28 July is not explained in the somewhat brief internal ADAS experiment report. However, examination of the weather data from nearby Marham is instructive (Barrie, I, 2006, personal communication). On the day of application there was no rainfall at Marham, but temperatures rose to 25.4^{0}C. The following day was similarly hot with 7.5 hours of sunshine. As for rainfall, 8.4 mm fell between 9.00 a.m. and 9.00 p.m. with a further 28.5 mm overnight. One could speculate that low humidity conditions on both the day of application and the following day impeded uptake, and then subsequent heavy rain leached MH from the crop canopy. Again, percent emergence from small tubers was greater than from large and this led to more daughter tubers being formed.

Optimum time for MH application

The best time for MH application for volunteer control seems to be five weeks before desiccation. The label for Source II recommends application from three to seven weeks before desiccation or the beginning of natural senescence. The Fazor label recommends application when the smallest tubers required to reach marketable size will be not less than 25 mm long. Typically, this will be 3 to 5 weeks before haulm destruction.

The Fazor label also has a reference to flowering (not present on the Source II label) which states "The last few flowers may still be apparent but most of the blossom will have already fallen". In view of the occasional cases of growth cracking seen when MH is applied early to late planted crops (i.e. they are physiologically young at the time of application) this aspect of the recommendation needs emphasising in the case of Fazor and including in the case of Source II.

Some of the US extension service websites specify a relatively mature crop before application. For example, the University of Wisconsin recommends application "two to three weeks after full bloom, when the smallest tubers that will be required to reach maximum size are 1.5 – 2 inches in diameter" (Internet ref. 9). This appears to be a slightly later timing than the Fazor recommendation. Similarly, the University of Maine recommends application for round varieties when the smallest tubers which will reach marketable size are at least 1.5 inches in diameter and 2 inches in diameter for Norchip. (Internet ref. 8). Also, "Do not apply earlier than two weeks past first bloom and do not apply later than two weeks before vine killing [haulm desiccation]". Again, the strong reference to the physiological maturity of the crop in terms of flowering and the larger tuber size recommendation than on the UK labels.

What the experimental data, the anecdotal evidence and the US recommendations imply is that GB growers need to pay more attention to the stage of crop maturity than that given on the current product labels, if yield effects and/or the risk of growth cracking are to be avoided. This is especially the case with late planted crops.

Care also needs to be taken with unirrigated crops, where heavy rain can on occasion instigate additional late tuber initiation. These later formed tubers may then exhibit growth cracking/malformation, even when MH is applied at the correct stage of foliage maturity.

REVIEW OF RESIDUES DATA FROM PSD AND OTHER SOURCES

Much of the early research on MH carried out primarily in North America concentrated on rate and timing of MH in relation to activity. In many cases residue analysis was carried out, which now provides useful background for comparison with more recent data.

Data from North America

Bishop and Schweers (1961) applied two rates of MH to potatoes in California, equivalent to 5.5 and 11 kg/ha of Fazor or Source (the UK recommended rate of application of both products being 5 kg/ha).

TABLE 23. RESIDUES OF MH IN CALIFORNIA (Bishop and Schweers 1961).

MH application lbs/acre	MH residue in tubers mg/kg			
	1958-59		1959-60	
	Sample range	Average	Sample range	Average
3	6-53	34	11-18	15
6	34-88	60	12-65	38

The large tuber-to-tuber variability in residues at each application rate is apparent, with more than nine-fold variability between the lowest and highest residue measured at the 3 lbs/acre rate in 1958-59. Note the average residue level only exceeded 50 mg/kg when more than twice the UK recommended rate of MH was used, and that only in one of the two years of the experiment. There appears to be a good relationship between rate of MH applied and residue, in that doubling the rate applied from 3 to 6 lbs/acre approximately doubled average residue levels in both years of the experiment. The data in these experiments are also interesting in that they report total yields, rather than US No. 1 yield (effectively graded yield) which other authors commonly use. This allows us to calculate percentage translocation of foliage applied MH to tubers.

TABLE 24. PERCENT RECOVERY OF MH IN TUBERS. Adapted from Bishop and Schweers (1961.)

	1958-59			1959-60		
MH kg/ha	Yield t/ha	Av. residue mg/kg	Recovery %	Yield t/ha	Av. residue mg/kg	Recovery %
3.3	22.86	34	23.5	11.49	15	5.2
6.6	22.86	60	20.7	12.23	38	7.0

1959 was much lower yielding than 1958 and percent recovery was much less. These data again emphasise the variability in uptake and likely activity from MH and the need for growers to take steps to minimise such variability.

Sawyer and Dallyn (1958) applied MH at 3 and 5 lbs/acre and measured maximum residues of 30.3 mg/kg.

Newsome (1980) working in Canada, applied the equivalent of 5 kg/ha of Fazor or Source II to potatoes. Samples were taken for residue analysis at weekly intervals beginning three weeks after treatment. Residues declined for several weeks, but it is not clear from the published paper why this should have been the case.

TABLE 25. DECLINE IN RESIDUES FOLLOWING MH TREATMENT (Newsome 1980).

Weeks after treatment	**MH residue mg/kg (4 sample mean)**
3	8.3
4	8.4
5	7.5
6	5.3
7	4.6
8	4.1
9	3.3
10	4.3

Such low residues as these would probably cause poor volunteer control in commercial practice.

GB research

Work at BPC (then PMB) Sutton Bridge in 1985 (Anon. 1986) measured total yield and residues of MH following treatment to commercial potato crops. Residues were measured both by Glasgow University and Uniroyal.

TABLE 26. BPC SUTTON BRIDGE. YIELD AND RESIDUES IN MH-TREATED COMMERCIAL CROPS (Anon. 1985).

Crop	**Total yield t/ha**	**Residue mg/kg**		**Recovery %**	
		Glasgow	Uniroyal*	Glasgow	Uniroyal*
Record 1	58.2	23.1	15.8	45	31
Record 2	54.0	7.5	6.4	13	12
M. Piper 1	63.0	17.0	14.1	36	30
M. Piper 2	58.6	5.7	3.8	11	8
P. Dell	34.2	21.7	13.9	25	16

* data are read from a chart and are approximate.

Maximum recovery in tubers was 45% of the applied dose, as measured by Glasgow University. Minimum recovery was only 8% as measured by Uniroyal. Looking at data from the individual laboratories, the range of recovery was approximately four fold at each, with the highest being Record 1 and the lowest Maris Piper 2.

In an experiment in Scotland, McKenzie (1989) measured a mean residue of 42.6 mg/kg, which is higher than other workers have reported for equivalent rates of MH application.

In the same experiment, the internal distribution of MH within tubers was measured in 6 tubers of 40-50mm diameter.

TABLE 27. INTERNAL DISTRIBUTION OF MH (McKenzie 1989).

	MH residue (mg/kg)	
	Mean	**Range**
Skin (0-2 mm)	30.1	12.5 - 56.4
Outer flesh (2-10 mm)	28.6	9.7 – 54.6
Core	22.7	12.0 – 44.5

A similar pattern of residue distribution within the tuber was noted within each tuber. In other words, tubers with low residue levels in the skin and/or outer flesh tended to have lower residues in the core of the tuber and *vice versa*. These data confirm the expected translocation of MH throughout the tuber flesh, although it appears that the core of the tuber tends to have lower residues than outer layers.

Dias and Duncan (1999) were also able to demonstrate relatively even distribution of MH throughout the tuber.

TABLE 28. MH DISTRIBUTION WITHIN TUBERS (Dias and Duncan 1999).

	MH residue (mg/kg)	
	Mean (± S.D.)	**Range**
Whole tuber	12 (±2)	11-14
peel	10 (±1)	9-10
Outer flesh	10 (±1)	10-11
Inner flesh	9 (±)2)	8-10

Free and bound MH

Residue studies by Smith *et al* (1959) were able to show that not all C^{14} labelled MH could be accounted for when experiments lasted a week or more, and the possibility of it becoming bound to proteins or glucoside, as indicated by other workers was discussed. Dias and Duncan (1999), working 40 years later, found no evidence for binding to glucoside, but acid hydrolysis could release MH which had become bound, and they speculated it could become bound to cell walls etc.

TABLE 29. BOUND MH RELEASED BY ACID HYDROLYSIS (Dias and Duncan 1999).

Sample description	**Treatment**	**MH residue (mg/kg)**		
		Before	After	Increase (±SD)
Old potatoes	β- glucosidase	5	5	0 (±1%)
Old potatoes	HCl	4	16	12 (±3%)
New potatoes	HCl	8	13	5 (±2%)

From an efficacy point of view, this research corresponds well with anecdotal evidence, indicating that volunteer control sometimes declines with time. If MH does become bound and inactive it will reduce the free pool of MH within cells able to inhibit sprouting, allowing more volunteers to emerge. It therefore appears that the application of MH should control sprouting of tubers left in the field long enough for other agents, especially those which are weather related, to finally kill them off.

Note that for measuring MH residues in potatoes, laboratories will normally only measure free MH rather than total MH (free plus bound MH).

More recent data

Experiments over two years, 2002 and 2003, each at four sites, conducted by Chiltern Farm Chemicals Ltd produced residues within the range 2.3 to 39.3 (Myram C, 2006, personal communication). Residues were analysed by Campden and Chorleywood Food Research Association (CCFRA). MH was applied 7, 5 and 3 weeks before anticipated desiccation, and residue analysis took place at harvest and after 1, 2 and 4 months of storage. The sample size for residue analysis was 12 to 24 tubers taken from a minimum of six plants.

TABLE 30. RESIDUES FROM EXPERIMENTS BY CHILTERN FARM CHEMICALS LTD. (unpublished).*

2002		Residue mg/kg			
Applied	**Analysis**	**Site 1**	**Site 2**	**Site 3**	**Site 4**
7 wks	Harvest	12.85	13.07	8.22	4.35
	1 month	12.57	11.22	9.43	6.16
	2 months	11.78	15.57	9.04	6.97
	4 months	16.41	10.77	8.65	5.34
5 wks	Harvest	13.94	30.26	11.63	6.93
	1 month	11.15	13.82	10.70	4.51
	2 months	11.48	13.94	7.60	5.18
	4 months	14.07	13.23	14.00	5.75
3 wks	Harvest	9.53	39.32	17.06	11.94
	1 month	4.54	31.63	8.24	14.04
	2 months	5.51	21.75	7.47	12.22
	4 months	7.24	13.75	5.09	12.52
2003					
7 wks	Harvest	3.93	4.85	7.33	16.49
	1 month	9.88	7.30	11.34	16.38
	2 months	3.33	2.38	9.30	10.85
	4 months	6.41	3.39	11.42	5.19
5 wks	Harvest	10.77	7.00	10.68	4.62
	1 month	6.67	8.33	20.58	9.58
	2 months	6.03	9.78	21.65	14.31
	4 months	11.94	5.40	9.63	8.15
3 wks	Harvest	16.91	9.85	10.35	2.52
	1 month	16.11	9.80	12.18	2.25
	2 months	14.15	6.25	6.97	5.43
	4 months	8.98	5.73	15.04	2.36

**NOTE. These data are the property of Chiltern Farm Chemicals Ltd and must not be reproduced without their express permission.*

One of the things which makes these experiments interesting is the sheer volume of residue data generated. There was some evidence of residues declining with time after harvest, as found by Newsome (1980) and Dias and Duncan (1999) especially at Sites 2 and 3 in 2002. But this was by no means consistent across all sites and there is clearly a lot of 'noise' in the data, as one would expect. However, the overall trend in residues was downward from 11.85 mg/kg at harvest, to 11.19 at one month after harvest, 9.97 at two months and 9.19 at four months. At Site 4 in 2003, uptake and translocation to tubers was clearly very poor.

Official PRC data published by PSD

Residue data from the Pesticide Residues Committee of PSD was neatly summarised by Bradshaw for the Food Standards Agency (Internet ref. 7) who combined ten years of pesticide monitoring in retail potatoes. This is the most comprehensive survey of residues in commercial crops in the UK and therefore deserves attention. Note that in 1998 there was no general survey of retail potato crops, only speciality (salad) crops, in which no MH was found, as one would expect. Therefore, 1998 is excluded from the table below.

TABLE 31. SUMMARY OF PRC RESIDUE DATA IN RETAIL CROPS (Internet ref. 7).

Year	Total samples	Samples with MH	Residue range mg/kg
1994	142	6	1.7-10.6
1995	139	16	1.5-16
1996	117	16	0.9-16
1997	122	13	6-17
1999	138	22	2.5-15
2000	134	27	1.6-23
2001	107	17	1.9-22
2002	144	10	1.3-17
2003	121	21	1.4-16
2004	56	24	3.1-20

MH residues were found within the range 0.9 to 23 mg/kg from all the samples collected over ten years. The data shows no residue exceeding even half the MRL of 50 mg/kg, but the number of very low residue readings throughout the eleven years implies poor application technology in many instances. Very low residues can in fact stimulate sprouting (Franklin and Lougheed 1964) which is not widely recognised and may account for some of the negative comments occasionally voiced by growers, especially regarding sprout control following the use of MH.

Processed potatoes show a similar picture, although potato products are not part of the PRC regular programme in their own right (Cooke, H, 2006, personal communication), so the data is not as extensive as for retail samples. One residue in crisps in 1994 was 42 mg/kg which is still well within the MRL, whereas in 1998 one residue was only 0.7 mg/kg, again implying poor application technology.

TABLE 32. SUMMARY OF PRC RESIDUE DATA IN PROCESSED CROPS (Bradshaw 2005).

Year	Total samples	Samples with MH	Residue range mg/kg
1994 (crisps)	47	10	4.1-42
1998 (pot. products)	52	18	0.7-11
2001 (pot. products)	78	13	1.3-8.4
2001 (crisps)	114	0	-

In addition, the PRC sampled chips bought from fish and chip shops in 2002. These were retail samples, purchased by shoppers employed by a market research company. The residue profiles were comparable with those from retail potato monitoring (Cooke, H, 2006, personal communication).

Likely worst-case residue scenario

It is easy to calculate what possible residues could be under a worst-case scenario. It is highly unlikely that any crop yielding less than 40 t/ha total yield would ever be treated with MH. At the other end of the scale, we do occasionally see crops yielding 75 t/ha total yield. At a rate of application of 5 kg/ha of a 60% MH produce, the amount of a.i. being applied is 3 kg/ha. In the published data, the best percent recovery in tubers of MH applied to foliage appears to be 45% and this would equate to a range of residues of 34-18 mg/kg depending on yield under optimum conditions. So although there may be occasions when an individual tuber could exhibit a residue above the 50 mg/kg MRL, the chances of a representative crop sample exhibiting such as residue appear to be remote.

This is especially the case because EU regulations regarding the collection of samples (Internet ref. 1) states "A MRL for a plant takes into account the maximum level expected to occur in a composite sample, which has been derived from multiple units of the treated product and which is intended to represent the average residue in a lot". The regulations require the collection of samples ranging from 1-2 kg. In other words, residues are measured from bulked samples and not individual tubers.

BRIEF REVIEW OF ALTERNATIVES TO MH IN ROTATIONAL POTATO VOLUNTEER CONTROL

The number of research papers published on the control of volunteer potatoes in other crops, not only in this country, but also abroad, shows just what a problem weed potatoes can be.

Turley (2001) provides an excellent and detailed account of research on rotational control of volunteers. This was a BPC/Defra funded LINK project carried out at three sites over several years. MH was included as an experimental treatment in a few instances in non-crop situations, *but was not applied to the potato crop itself*, and was probably applied too early to the emerged volunteers to have significant effects on daughter volunteer emergence the following year (Turley D, 2006, personal communication). It is therefore important not to misinterpret the data as implying that MH applied to the potato crop does not give useful rotational control of volunteers, because no such conclusion could be drawn from these experiments.

The extent of the problem in following crops

Lutman (1977), working at the then Weed Research Organisation (WRO) based near Oxford, reported experiments in England quantifying the size of the problem. His work was part-funded by the PMB (now BPC). At seven sites the number of volunteers recorded ranged from 119,000 to 367,000/ha. Of these, over 80% of volunteer tubers were between 10 and 40 mm in diameter. Nearly 30% were on the soil surface, whilst 39% were in the top 5 cm of soil and 32% deeper than 5 cms. In an experiment where tubers were planted in December 1974, more than 90% of tubers of tubers planted 2.5 – 20.0 cm deep in December 1974 survived. Similarly, where tubers were planted approximately 5 cm below the soil surface, 57% survived. However, there were fifteen occasions when the temperature at the soil surface (grass minimum) fell below –4^{o}C and two where it fell below –8^{o}C.

Lutman recorded between 1.2 and 1.9 tubers per plant from volunteers present after a winter wheat crop towards the end of August. The higher numbers per plant tended to be from Maris Piper volunteers. Following spring barley and spring wheat, when Pentland Crown was grown, numbers per plant ranged from 2.5 to 3.4.

Quoting both Dutch and WRO work on volunteers, Lutman points out that overwinter survival can be as high as 70% or more in some experiments. Also, more volunteer plants emerge in non-competitive crops such as sugar beet than competitive ones such as winter wheat. He suggests that potatoes may compete with wheat for soil moisture in the spring, which may delay their emergence, and a dense wheat canopy will reduce soil temperatures and further delay emergence.

In Holland, Lutman quotes work where in winter wheat, potato volunteers produced an average of 2.6 tubers per plant and in sugar beet, 3.9 tubers per plant. Crop competition clearly has a large effect on the volunteer problem.

In a survey of potato growers in Scotland, 90.3% of respondents noted that volunteer potatoes presented a problem (Davies K. 2001, internal report to SEERAD).

Turley (2001) reported ranges of potential volunteers left at three sites. At ADAS High Mowthorpe, he recoded 74,000 to 112,000/ha, at ADAS Rosemaund 30,000 to 112,000/ha and at Sacrewell 12,000 to 192,000/ha. He commented that the level of tuber loss by harvesters is no better than it was twenty years ago, and that the volunteer problem is increasing, due to pressure on rotations as well as milder winters reducing winter kill and rotting. He also comments that very high levels of virus infection were found in volunteers from ware crops, with 60-80% of tubers with PVY in affected fields.

The role of glyphosate

The introduction of the non-selective translocated herbicide glyphosate to the UK in the early 1970's sparked interest in controlling volunteers in cereal stubbles (Lutman 1979a). In a series of experiments, artificial populations of volunteers were established in winter or spring barley crops, using either Pentland Crown or King Edward 30-50 mm tubers planted 5 cm deep. Following cereal harvest, stubbles were sprayed with either aminotriazole or glyphosate. The percentage potato volunteers with emerged shoots appeared to be related to the vigour of the cereal crop. In one very vigorous winter barley crop, only 25% of planted tubers had emerged pre-harvest, whereas in less vigorous spring barley nearly all had emerged by early June.

TABLE 33. POTATO SHOOTS PER PLOT, ASSESSED JUNE 1977, FOLLOWING TREATMENT WITH GLYPHOSATE IN 1976 IN BOTH WINTER AND SPRING BARLEY STUBBLES (Lutman 1979a).

		glyphosate kg/ha ai		
	Date of application	**0.75**	**1.5**	**3.0**
Winter barley	06/9/1976	*0.7*	*1.0*	*1.0*
	28/9/1976	*0.3*	*2.0*	*0*
	13/10/1976	*0.3*	*0*	*2.3*
	Control		*6.8*	
	SE of treatments		0.87	
	SE of control		1.72	
Spring barley	13/10/1976	*7.2*	*13.0*	*11.2*
	Control		*14.0*	
	SE of treatments		1.98	
	SE of control		0.75	

Lutman noted that control achieved by glyphosate reflected the degree of regrowth of potatoes following cereal harvest. Good regrowth in winter barley stubbles was followed by good control by glyphosate, whereas poor regrowth in spring barley stubbles was followed by poor control. Crop competition, drought and harvest date, all of which affect regrowth, will influence the outcome of glyphosate treatment. In the winter barley experiment, there were similar average levels of herbicide performance at the different dates of application, indicating that the level of control is related to the percentage of plants that regrow and not their size. Lutman suggested that stubbles should be left for approximately 4 weeks after cereal harvest to allow adequate regrowth. The variability in the performance of glyphosate seen in these experiments will be familiar to potato growers and emphasises that there is no one solution to the problem of volunteers.

Merritt and Edwards (1993) carried out experiments with glyphosate using natural populations of volunteer potatoes. Pre-wheat harvest application in the dry summer of 1990 showed no effect of glyphosate dose rate either on foliage kill or percent control the following year. In contrast, autumn stubble treatment did show a dose response both in terms of foliage kill and volunteer control in the year after application.

TABLE 34. PERCENT FOLIAR KILL AND SUBSEQUENT CONTROL OF VOLUNTEERS FOLLOWING PRE AND POST-CEREAL HARVEST TREATMENT WITH GLYPHOSATE (Merritt and Edwards 1993).

	Glyphosate g/ha a.i.			
	540	**720**	**1080**	**1440**
Pre-harvest				
Foliar kill 14 DAT*	*11*	*5*	*19*	*21*
Control 1 YAT*	*68*	*66*	*70*	*70*
Post-harvest				
Foliar kill 14 DAT	-	*72*	*85*	*91*
Control 1 YAT	-	*55*	*71*	*80*

*DAT = days after treatment. YAT = year after treatment.

The authors noted that the variable emergence pattern of volunteers is a major factor interfering in control using glyphosate. Results from other experiments carried out by Monsanto have confirmed the dose/response nature of glyphosate (Sansom M, 2006, personal communication) and it is now broadly accepted in the industry that the highest label rate of glyphosate should be used for post-cereal harvest potato volunteer control.

Cultivation and frost

Cleal *et al* (1993) investigated integrated control programmes in cereals and sugar beet, including glyphosate pre and post cereal harvest. Here, 25-35 or 25-45 mm tubers were distributed on the soil surface at three ADAS experimental farms (Arthur Rickwood, Terrington and Gleadthorpe) and either ploughed or cultivated in. It was noted that non-ploughing treatments substantially reduced volunteer populations the following year, but only when accompanied by frosty weather that would freeze tubers close to the soil surface. Also, post-harvest glyphosate applied in the dry summer of 1991 did not significantly reduce volunteer populations the following year, because of limited foliage regrowth after the cereal harvest. One of the conclusions of the research at ADAS Arthur Rickwood was that the best control of volunteers came about through not ploughing for two winters after potatoes (Cleal 1992, personal communication). This can be possible where wheat follows potatoes and a spring crop such as sugar beet follows wheat, as long as potatoes are harvested in good conditions. If not, then farmers have little option but to plough in order to establish a winter wheat seedbed.

Bevis and Jewell (1986) reported on the effect of cultivation treatments at ADAS Arthur Rickwood in the mid 1980s. These clearly demonstrated the benefits of not ploughing after potatoes at that time.

TABLE 35. EFFECTS OF CULTIVATIONS ON VOLUNTEER POPULATIONS (PLANTS/M^2). Bevis and Jewell 1986.

	Ploughed and cultivated	Cultivated only	SED
Mean of cereal herbicide treatments on day of spraying	2.75	0.25	0.802
Mean of untreated cereal plots assessed Aug 1985	3.50	0.75	0.785
Mean of all plots assessed Aug 1985	1.45	0.25	0.381
Mean of all plots in 2nd wheat Aug 1986	1.81	0.45	0.133

The effect of not ploughing at that time was dramatic. However, during the winters of 1984-85 and 1985-86, severe weather persisted for some time (Lutman 1986) which would bias results towards non-plough treatments. Experience would indicate that following a mild winter, volunteers in unploughed fields emerge swiftly and are very vigorous, whereas in ploughed fields they tend to emerge later over a prolonged period of time and are less vigorous. In such circumstances, which cultivation treatment is the better then depends on how aggressively volunteers are pursued with herbicides. The effect of a relatively cold winter on volunteers populations tends to be dramatic, whether or not fields are ploughed. Certainly in 2006, following a colder winter than for several years, volunteer populations in sugar beet were noticeably lower, emerged later and were less vigorous than the industry has become used to dealing with in recent years.

Research in Washington State (Thomas and Smith 1983) over two years emphasised the effect of weather, in that the best control of volunteers was achieved by waiting after harvest until tubers on the surface were frosted before engaging in any cultivation. Mid-winter ploughing after the first severe frosts further reduced volunteer numbers, but that is unlikely to work on a regular basis in GB, simply because of the scarcity of severe frosts. Interestingly, treatment with 1,3-dichloropropene + chloropicrin (Telone C) proved to be effective in reducing volunteer numbers when combined with autumn ploughing. This was because ploughing placed the tubers deep in the soil where they would be exposed to the fumigant at greater concentrations for longer periods than if left close to the soil surface. In the UK, 1,3-dichloropropene is sold without chloropicrin (Telone II rather than Telone C). Both active ingredients are phytotoxic and so Telone II should give at least some control of volunteers, although this is rarely, if ever, mentioned in connection with volunteer control in this country.

TABLE 36. VOLUNTEERS PER PLOT (2.8 X 24M) APPEARING THE FOLLOWING SPRING IN THE ABSENCE OF A COVER CROP (Thomas and Smith 1983).

	Ploughing date			
Treatment	**None**	**1 Oct**	**15 Dec**	**1 April**
Control	137a	404a	65a	127ab
MH 2 wks*	83a	273b	41a	65b
MH 4 wks*	71a	341a	84a	171a
'Telone C' 3 Oct	112a	71c	50a	139ab
'Telone C' 20 March	102a	47c	52a	119ab

* MH applied 2 or 4 weeks after full bloom (flowering).
Letters compare chemical treatments within each cultivation practice (columns). Different letters indicate means are different at 5% probability level.

The data in the table above come from the second year of the experiment, when the performance of MH was poor. In the first year it was much better (see Inconsistent volunteer control).

The benefits of leaving the ground not ploughed after potatoes is emphasised by data from Washington State (Internet ref. 10) where 66% were up to 5 cms deep, 28% 5-10 cms deep and only 6% 10-15 cms deep. Ploughing can clearly bury these tubers near the soil surface and protect them from freezing.

Volunteer control in sugar beet

In sugar beet, suppression of volunteers has focussed on the use of clopyralid (Dow Shield) in herbicide sequences, with or without the addition of ethofumesate and/or triflusulfuron-methyl (Debut). May and Hilton (1993) planted Desiree 'volunteer' potatoes in sugar beet in two experiments. Daughter tubers were harvested, stored overwinter and planted out the following spring, when foliage growth and yield of granddaughter tubers were assessed.

TABLE 37. SOME HERBICIDE TREATMENTS IN SUGAR BEET FOR THE CONTROL OF VOLUNTEER POTATOES (May and Hilton 1983).

Herbicide sequence g. ai/ha		**Year of application**		**Following year**	
T1	**T2**	**Foliage Vigour score**	**Tuber yield kg/plot**	**Foliage Vigour score**	**Tuber yield kg/plot**
clop 50	as T1	*6.3*	*0.375*	*9.5*	*6.54*
clop 100	as T1	*4.0*	*0.308*	*6.8*	*3.04*
phen 285 + etho 300	as T1	*5.5*	*0.119*	*7.0*	*6.62*
clop 100 + phen 285 + etho 300	as T1	*4.5*	*0.108*	*7.5*	*1.92*
Control	Control	*9.8*	*0.560*	*9.5*	*10.57*
SED (57 d.f.)		0.7	0.049	1.08	1.21

clop 50 — clopyralid 50 g/ha, equivalent to 0.25 l/ha Dow Shield
clop 100 — clopyralid 100 g/ha, equivalent to 0.5 l/ha Dow Shield
phen 285 — phenmedipham 285 g/ha, equivalent to 2.5 l/ha of a 114 g/l product
etho 300 — ethofumesate 300 g/ha, equivalent to 1.5 l/ha of a 200 g/l product
Vigour score: 10 = normal, healthy 0 = dead

There was a trend for mixtures of clopyralid + phenmedipham + ethofumesate to perform better than clopyralid treatments alone, or phenmedipham + ethofumesate treatments alone. Clopyralid + phenmedipham + ethofumesate treatments have become standard mixtures to use in sugar beet when targeting potato volunteers.

In the late 1990's, the sulfonyl urea herbicide triflusulfuron-methyl (Debut) became available as a sugar beet herbicide, which can increase the effect both on foliage vigour in the year of application and foliage vigour the following year (Chisholm 1998). It is normally used in a tank mix with lower rates of the active ingredients than those described above.

Experience suggests that volunteers damaged by herbicides applied to sugar beet often die prematurely. This is probably due to the effects of drought. Sugar beet frequently abstracts soil moisture to a depth of 1.8m, whereas even normal potato crops rarely abstract soil moisture below 0.7m. Herbicide damaged volunteers are likely to abstract moisture to only shallower depths than that. In other words, they quickly lose out to sugar beet in the battle for soil moisture.

Volunteer control in cereal crops themselves

In cereal crops, control of potato volunteers has centred on the use of fluroxypyr (Starane or similar), with or without the addition of a sulfonyl urea herbicide, especially metsulfuron-methyl (as Ally or similar). In the work of Cleal et al (1993) cereal treatments included both fluroxypyr +/- metsulfuron methyl. In a dry season (1991) at both ADAS Terrington and ADAS Arthur Rickwood, effects from cereal herbicides were relatively small. In the year following treatment, there was some reduction in percent ground cover by volunteer potatoes (data not shown).

TABLE 38. EFFECT OF CEREAL HERBICIDES ON POTATO VOLUNTEERS IN THE YEAR OF APPLICATION (Cleal *et al* 1993). Treatment effects measured on 12 August

	Stem no./m^2	**Height cms**	**Vigour**
metsulf. + fluroxy.	2.97	44.2	5.7
fluroxypyr	3.25	29.5	6.3
Control	3.91	64.6	7.0
SED	NS	6.33 (8 d.f.)	0.66 (19 d.f.)

metsulf + fluroxy = metsulfuron-methyl (6 g/ha)+ fluroxypyr (200 g/ha), equivalent to Ally 30 g/ha + Starane 1 l/ha, applied at GS 39, full flag leaf emerged.
fluroxypyr @ 400 g/ha, equivalent to Starane 2 l/ha, applied at GS 45, flag leaf sheath opening.

Metsulfuron-methyl and fluroxypyr are widely used herbicides in cereals. However, they tend to be used at lower rates than those described above, typically 3-4 g/ha metsulfuron-methyl and 100-150 g/ha fluroxypyr and at timings when many volunteers may not have even emerged (Bellamy J. 2006, personal communication) and so their effects on rotational volunteer control can be expected to be small. In terms of timing, if using fluroxypyr to specifically target volunteer potatoes, Graham et al (1987) concluded that best control would be achieved by an application when volunteers were 15-20 cms high, which would tend to coincide with winter cereals at

GS 39. However, Ogilvy e*t al* (1989) commented that groundkeepers are still emerging when cereal crops reach GS39, and although fluroxypyr is now approved for use in winter wheat up to GS45, the timing difference is insufficiently large to have a material effect on this conclusion.

Bunn et al (1986) noted varietal differences in susceptibility to fluroxypyr with relatively high rates of application (equivalent to 1.5 or 2.0 l/ha Starane), but there appears to be little or no anecdotal evidence to confirm their findings. However, that again may be related to the lower rates used commercially in cereals. They made the interesting observation that all rates tested prevented flowering and therefore seed production.

Volunteer control in other root crops

Onions are often grown in rotation with potatoes, and it is very common to see potato volunteers in onion crops. Herbicides have tended to become dominated by sequences of ioxynil + cyanazine + fluroxypyr with rates and timings adjusted to the growth stage of the crop, weeds present and their growth stage (Sheppy R, 2006, personal communication). Bond (1993) experimenting at HRI Wellesbourne in a range of vegetable crops with ioxynil, fluroxypyr and clopyralid, concluded that treatments containing fluroxypyr caused the most injury to potato volunteers (Cara), but no treatment controlled them completely.

Carrots too are frequently grown in rotation in rotation with potatoes. Up to now, metoxuron has been the backbone of potato volunteer in carrots, but Approval is being withdrawn in 2007 and it is not clear what, if anything will be available to take its place (Wells A, 2006, personal communication). It could be that weed wiping with glyphosate, relying on the height difference between the crop and the volunteers, will be the only means of control available. If that is the case, it is likely put more pressure on potato growers to control volunteers elsewhere in the rotation, perhaps including increased use of maleic hydrazide. The effects of metoxuron on potato volunteers are documented in the experiments of West and Richardson (1987). The effects of a range of herbicides, including metoxuron, on volunteer potato seedlings derived from true seed, were recorded by Lawson and Wiseman (1984).

Soil applied herbicides

Soil applied herbicides are most unlikely to offer any real hope of controlling potato volunteers. Lutman (1977b) assessed soil-applied chlorpropham, propyzamide and trifluralin in experiments. Chlorpropham was insufficiently active, but trifluralin and propyzamide at 4-12 kg/ha reduced and delayed emergence of volunteers, but good activity depended on the herbicide completely surrounding the tubers when active growth began in the spring. Also, residues of these herbicides at these rates were damaging to following crops.

GAPS IN OUR KNOWLEDGE REQUIRING FURTHER RESEARCH

The difficulties in carrying out research on potato volunteers which yields statistically significant results should not be underestimated. This was summarised neatly by Ogilvy *et al* (1989) who point out that relying on field populations of volunteers results in extremely uneven populations on which to test treatments, whereas artificial populations allows easier interpretation of results, but do not emulate natural field conditions where tubers of varying size and depth emerge more unevenly.

The effect of soil type on volunteer numbers. Experience strongly suggests much higher volunteer populations emerge as a problem on lighter rather than heavier soils. This may be due to lower tuber numbers being set on heavier soils so there are fewer left behind in the field at harvest. Another possibility is that more tubers rot in wet winter soils. Or perhaps another unknown factor is at work, but this phenomenon is worth investigating.

The control of volunteers according to tuber size. Anyone who has tried to control volunteers in arable crops knows that numbers is only part of the issue. The vigour of volunteers is also important and that is largely related to tuber size (and probably also the depth from which they emerge). This is not well documented.

Water volumes and spray quality in the application of MH. Windows for applying MH, which combine suitable weather conditions with the correct growth stage of the crop, are often few and far between. This can mean having to spray a large hectarage at a time of year that coincides with cereal harvest. Early US and UK experiments found good activity from aerial application at exceeding low volumes relative to the 300/350 l/ha minimum recommended on current labels. This needs revisiting.

Timing of MH application in relation to desiccation and senescence. The optimum timing for activity appears to be around 5 weeks before desiccation. But does that apply to senescence too? Especially with crisping crops, where nitrogen is often restricted in order to guarantee maturity, senescence can begin a long time before desiccation and it is not uncommon to see it well underway only a couple of weeks after MH application. What effect that has on MH activity is unknown.

The effect of volunteers in maintaining PCN populations and soil borne diseases. The lack of data on this subject area, especially that related to PCN, is somewhat surprising. In terms of soil borne diseases which may be carried over by volunteers, one thinks primarily of skin blemish diseases such as black scurf, black dot and silver scurf, but also others which may be yield debilitating, such as *Verticillium* spp.

The depletion of free MH during storage. The work of Dias and Duncan (1999) clearly shows MH does become bound and inactive with time after application. This extent to which this can occur requires further investigation, because of its huge potential influence on volunteer control.

The use adjuvants to improve the reliability of uptake and activity. Some early experiments with MH reported poorer uptake when humidity at the time of application was below 80%. For example, see Franklin and Lougheed (1964). From such experiences it would not be unreasonable to assume that the addition of a suitable adjuvant oil might improve uptake. The use of adjuvant oils is routine with sugar beet herbicides and they are known to improve uptake and activity. Also, adjuvants which accelerate uptake would reduce the deleterious effects of rain falling soon, or even not so soon after application. It has been reported that rain falling within 16 hours of application will reduce the effect of MH, but when applied with an emulsifiable oil, rain is likely to reduce the effect only if it falls within 6 hours (Anon. 1958). In GB, finding weather conditions combining above 80% RH with a dry forecast for the following 24 hours within the growth stage window of the crop is no mean feat. From comments in the published literature and anecdotal experience, it would appear that experiments using adjuvants in order to reliably improve uptake are justified.

The biology of volunteers. Lutman (1986) points out that the emergence of volunteers in autumn sown crops is later than in spring sown and potatoes in winter cereals will emerge as late as July. Turley (2001) noted that potato volunteers started to emerge in winter wheat in May or June and would continue to emerge up to August, when wheat was harvested. Also, flushes of volunteer emergence were commonly recorded in the autumn after a first wheat harvest. Lutman speculates that warmer soil conditions and greater availability of soil moisture favours earlier emergence in spring sown crops. This takes some believing and one suspects there is something more fundamental going on here, perhaps related to the inhibition of dormancy break by cereals. This aspect of volunteer biology certainly deserves some research.

ACKNOWLEDGEMENTS

Steve Gerrish, BPC Oxford - literature searches.
Adrian Briddon, BPC Sutton Bridge - research contacts in North America.

REFERENCES

Anon. (1958). Weed Control Handbook. 1st Edition. Blackwell.

Anon (1977). Approved products for farmers and growers. 1st Edition. MAFF. HMSO.

Anon. (1987). Maleic hydrazide for the control of sprouting in store. In: Sutton Bridge Experimental Station, Annual Review 1986. Potato Marketing Board.

Anon. (1988). Maleic hydrazide for the control of sprouting in store. In: Sutton Bridge Experimental Station, Annual Review 1987. Potato Marketing Board.

Anon (2003). Pesticide Manual. 9th Edition. Edited by Tamlin CDS. BCPC.

Bevis AJ and Jewell SN (1986). Preliminary results from the use of chemicals or cultivation to control potato groundkeepers. Conference proceedings. Crop protection of sugar beet and crop protection and quality of potatoes: part II. Aspects appl. Biol. 13, 201-208.

Bishop JC and Schweers VH (1961). Sprout inhibition of fall-grown potatoes by airplane application of maleic hydrazide. Am. Potato J. 38, 377-381.

Bond W (1993). Evaluation of ioxynil, fluroxypyr and clopyralid for the control of volunteer potato in vegetable crops. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. 35, 123-130.

Bunn FE, Jeffery, PJ and Graham JC (1986). Investigations into the control of volunteer potatoes in cereals in the UK with applications of fluroxypyr alone or in tank mix with clopyralid. Conference proceedings. Crop protection of sugar beet and crop protection and quality of potatoes: part II. Aspects appl. Biol. 13, 209-217.

Burton W G (1978). Chapter 14. The Physics and Physiology of storage. In: Harris P M (ed.) The Potato Crop. The Scientific Basis for Improvement. Chapman and Hall.

Chisholm C (1998). Debut for volunteer potato control in sugar beet. British Sugar Beet Rev. 66, 12,14.

Cleal RAE, Hayward CF, and Rawlings PJ (1993). Integrated control of volunteer potatoes in cereals and sugar beet. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. 35, 139-148.

Davis JR and Groskopp MD (1981). Yield and quality of Russet Burbank potato as influenced by interactions of *Rhizoctonia,* maleic hydrazide, and PCNB. Am. Potato J. 58, 227-237.

Denisen EL (1953). Response of Kennebec potatoes to maleic hydrazide. Proc. Am. Soc. Hortic. SCI. 62, 411-421.

Dewar AM, Haylock LA, May MJ, Beane J and Perry RN (2000). Glyphosate applied to genetically modified herbicide-tolerant sugar beet and 'volunteer' potatoes reduces populations of potato cyst nematodes and the number and size of daughter tubers. Ann. appl. Biol. 136, 179-187.

Dias AI and Duncan J (1999). Residues of free and bound maleic hydrazide in potato tubers. Potato Research 42, 89-93.

Franklin EW and Thompson NR (1953). Some effects of maleic hydrazide on stored potatoes. Am. Potato J. 30, 289-295.

Franklin EW and Lougheed EC (1964). The rate and amount of absorption of maleic hydrazide by potato tubers. Am. Potato J. 41, 191-195.

Graham JC, Bunn FE and Jeffery PJ (1987). The control of volunteer potatoes with fluroxypyr in UK cereals. Conference proceedings. British Crop Protection Conference – Weeds, 241-247.

Heath MC, Ward JT and Rogers-Lewis DS (1993). Optimising timing of application of maleic hydrazide on potatoes for control of volunteers in subsequent crops. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. 35, 167-171.

Hinchcliff K, Bunn F and Taylor W (1993). Suppression of volunteer potatoes following the application of maleic hydrazide to main-crop potatoes. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. 35, 173-174.

Kennedy EJ and Smith O (1951). Response of the potato to field application of maleic hydrazide. Am. Potato J. 28, 701-702.

Kennedy EJ and Smith O (1953). Response of seven varieties of potatoes to foliar applications of maleic hydrazide. Proc. Am. Soc. Hortic. Sci. 61, 395-403.

Lainsbury MA, Hilton JG and Pollack R (1998). Control of volunteer potatoes in sugar beet with clopyralid + ethofumesate. Conference proceedings. Protection and production of sugar beet and potatoes. Aspects appl. Biol. 52, 387-392.

Lawson HM and Wiseman JS (1984). The post-emergence activity of ten herbicides on volunteer potato seedlings Ann. appl. Biol. (supplement). Tests of Agrochemicals and Cultivars, **5**, 86-87.

Lutman PJW (1977). Investigations into some aspects of the biology of the potato as weeds. Weed Res. **17**, 123-132.

Lutman PJW (1977b). Studies on the control of groundkeeper potatoes with the soil-applied herbicides chlorpropham, propyzamide and trifluralin. Pestic. Sci. **8**, 637-646.

Lutman PJW (1979). The control of volunteer potatoes in the autumn in cereal stubbles. II. The performance of glyphosate and aminotriazole. Ann. appl. Biol. **93**, 49-54.

Lutman PJW (1979). The effects of topical applications of glyphosate and aminotriazole on volunteer potatoes (*Solanum tuberosum*). Weed Res. **19**, 377-383.

Lutman PJW (1986). The biology and control of groundkeeper potatoes: a review. Conference proceedings. Crop protection of sugar beet and crop protection and quality of potatoes: part II. Aspects appl. Biol. **13**, 177-184.

May MJ and Hilton JG (1993). Control of volunteer potatoes in sugar beet. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. **35**, 89-96.

Merritt CR and Edwards RV (1993). Developments in the use of glyphosate for the control of volunteer potatoes. Conference proceedings. Volunteer crops as weeds. Aspects appl. Biol. **35**, 175-178.

Newsome WH (1980). Residues of maleic hydrazide in field-treated potatoes. J. Agric. Food Chem. **28**, 1312-1313.

Ogilvy SE, Cleal RAE and Rogers-Lewis DS (1989). The control of potato groundkeepers in cereal crops. Conference proceedings. Brighton Crop Protection Conference – Weeds, 205-212.

Paterson DR, Wittwer SH, Weller LE and Sell HM (1952). The effect of preharvest foliar sprays of maleic hydrazide on sprout inhibition and storage quality of potatoes. Plant Physiol. **27**, 135-142.

Peddie AS, Bartlett DH and Taverner PB (1986). Pre-harvest application of maleic hydrazide to potatoes to suppress volunteers in succeeding crops. Conference proceedings. Crop protection of sugar beet and crop protection and quality of potatoes: part II. Aspects appl. Biol. **13**, 219-225.

Sawyer RL (1967). Chapter 6, Sprout inhibition. In: Talburt WF and Smith O. Potato Processing, 2nd Edition. Avi Publishing, Connecticut.

Sawyer RL and Dallyn SL (1958). Timing of maleic hydrazide to stage of plant development. Am. Potato J. **35**, 620-625.

Smith AE, Zukel JW, Stone GM and Riddell JA (1959). Factors affecting the performance of maleic hydrazide. J. Agric & Food Chem. **7,** 341-344.

Thomas PE and Smith DR (1983). Relationship between cultural practices and the occurrence of volunteer potatoes in the Columbia Basin. Am. Potato J. **60**, 289-294.

Weis GG, Schoenemann and Groskopp MD (1980). Influence of time of application of maleic hydrazide on the yield and quality of Russet Burbank potatoes. Am. Potato J. **57**, 197-204.

West TM and Richardson WG (1987). Pot experiment to investigate the control of volunteer potatoes, at three growth stages, with six post-emergence herbicides. Ann. appl. Biol. (supplement). Tests of Agrochemicals and Cultivars, **8**, 120-121.

Yada RY, Coffin RH, Keenan MK, Fitts M, Dufault C and Tai GCC (1991). The effect of maleic hydrazide (potassium salt) on potato yield, sugar content and chip color of Kennebec and Norchip cultivars. Am. Potato J. **68**, 705-709.

BPC Research Reports

1. Buckley DC (1998). Practical techniques for the control of internal rust spot. BPC research publication No. 807/191.

2. Turley D (2001). Understanding the biology and incidence of potato volunteers. BPC research publication No. 807/151.

References currently available on the internet

1. Official Journal of the European Communities. Commission Directive 2002/63/EC of 11 July 2002 establishing Community methods of sampling for the official control of pesticide residues in and on products of plant and animal origin and repealing Directive 79/700/EEC.
http://europa.eu.int/eur-lex/pri/en/oj/dat/2002/l_187/l_18720020716en00300043.pdf

2. Official Journal of the European Union. Commission Directive 2003/31/EC of 11 April 2003 amending Council Directive 91/414/EEC to include 2,4-DB, beta-cyfluthrin, cyfluthrin, iprodione, linuron, maleic hydrazide and pendimethalin as active substances.
http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=32003L0031&model=guichett

3. Official Journal of the European Union. Commission Directive 2005/37/EC of 3 June 2005 amending Council Directives 86/362/EC and 90/642/EC as regards the maximum levels for certain pesticide residues in and on cereals and certain products of plant origin, including fruit and vegetables.
http://eur-lex.europa.eu/LexUriServ/site/en/oj/2005/l_141/l_14120050604en00100023.pdf

4. Central Science Laboratory. Pesticide Usage Statistics.
http://pusstats.csl.gov.uk

5. Crompton USA. Material Data Safety Sheet for Royal MH-30SG.
www.cdms.net/ldat/mp806014.pdf

6. Crompton USA. Royal-30 MH Xtra. Product label.
www.cdms.net/ldat/ld806013.pdf

7. Bradshaw N (2005). Food Standards Agency. Pesticide residue minimisation crop guide (draft). www.food.gov.uk/Consultations/ukwideconsults/2006/residueguide2

8. The University of Maine. Cooperative Extension. Potato Pest Management Guide 2005.
www.mainepotatopestguide.com/potatosproutinhibitors.asp

9. Potato Production in Wisconsin 2002.
http:/ipcm.wisc.edu/piap/potato.htm

10. University of Idaho. College of Agriculture. Cooperative Extension System. http://info.ag.uidaho.edu/Resources/PDFs/CIS1048.pdf

11. UN FAO. Maleic Hydrazide.
www.fao.org/ag/AGP/AGPP/Pesticid/JMPR/Download/98_eva/MaleicH.pdf