THE PLACE OF HERBICIDES IN THE POTATO CROP

R. J. STEPHENS
Scottish Horticultural Research Institute, Invergowrie, Dundee, Scotland

Zusammenfassung, Résumé, p. 44

SUMMARY

Cultivation of potato fields after planting is shown to be primarily for weed control and only of limited benefit to the crop itself. Yields have often been reduced by an excessive number of post-planting cultivations. The conventional management system using frequent post-planting cultivations has the disadvantage of increasing the spread of potato virus X, encouraging the formation of stable soil clods in the ridges by the passage of implements, and increasing susceptibility of the crop to frost after emergence. Moreover, the need for inter-row cultivation imposes a limitation on the spatial arrangement of plants in the field.

The potato is highly susceptible to weed competition, but comparatively indifferent to the degree of post-planting cultivation. If herbicides are to replace cultivation as a method of weed control they must be effective and leave no toxic residue in the tubers. Suitable herbicides, many of them mixtures, have been found and specific local recommendations have been made. No single herbicide or mixture of herbicides is likely to be successful under the wide range of growing conditions and weed problems met in practice. The implications of replacing cultivation with herbicides are being widely investigated but so far no alternative to the system of plant arrangement in standard use has shown an outstanding advantage.

1. INTRODUCTION

Over 10 years ago ALDRICH and CAMPBELL (1952), working in New Jersey, showed that the greater part of the intensive post-planting cultivations normally associated with the potato crop could be dispensed with if herbicides were used. Some 5 years later in Germany, RADEMACHER (1957) described the way in which chemical weed control could be integrated with older method of husbandry. Interest in these developments was not aroused in Britain until it was discovered that hard soil clods, which are the most difficult part of the soil to separate mechanically from potato tubers, are formed largely as a result of post-planting cultivations (N.I.A.E., 1958–59). Experiments at several centres in Europe continued (PÄTZOLD, 1959; ROBERTSON 1960a and b; WOOD, SUTHERLAND and STEPHENS, 1960), and many workers have now described the succesful substitution of herbicide treatment for post-planting cultivation, sometimes with an increased yield. In consequence there is now considerable interest amongst potato growers in the use of herbicides such as linuron, monolinuron, a commercial mixture of simazine with prometryne, paraquat, diquat, and various formulations of dinoseb.

Accepted for publication 26th January, 1965.

Such a major change in husbandry cannot be considered in isolation, because the management and spacing of the crop has been influenced for so long by the need for post-planting cultivations to control weeds. In the following account some of the implications of adopting herbicides are considered. Chemicals used for haulm destruction and growth regulators applied to the foliage at low concentrations to modify plant growth are not discussed.

2. THE HARMFUL EFFECT OF WEEDS ON THE CROP

Many authors have shown that weeds compete effectively with potatoes for water and nutrients, and if not controlled, yields may be severely reduced (NEILD and PROCTOR, 1962; STEPHENS, 1962, 1964; INGRAM, 1964; GREIG and AP-TIKRITI, 1962; BECKER, 1962). BURGHAUSEN (1963a) suggests that the competitive effect of weeds depends on the predominant species present. Specific interactions between certain weed and crop species (including potatoes) have been demonstrated in water culture (MARTIN and RADEMACHER, 1960), but the importance of these phenomena in the field is unknown. Since most annual weeds germinate near the surface (CHANCELLOR, 1964), they are unlikely to affect the crop until after it has emerged; PEREIRA (1941) has shown, however, that even if the weeds present at emergence are very small they can still cause a reduction in yield. Once well emerged and growing actively, potato plants seem to be rather less susceptible to weed competition than at the time of emergence (VAN HIELE, 1952; KAWATEI, KITANO and SHIRASAWA, 1958). In practice it is rarely possible to achieve complete weed control by cultivation for a variety of reasons including bad weather, and NEURURER (1961a) estimates that potato yields in East Germany could be increased by 10% if weed competition could be eliminated by improved methods of husbandry.

A tangle of weeds during lifting can increase the number of tubers left in the ground (FISCHNICH, 1958), increase mechanical damage (SAWYER and DALLYN, 1963), and increase the time taken to lift the crop (NATION, 1961). Furthermore, tubers may be pierced by rhizomes of couch grass (*Agropyron repens*), Bermuda grass (*Cynodon dactylon*), or nut grasses (*Cyperus* spp.) (ENNIS, SHAW, DANIELSON, KLINGMAN and TIMMONS, 1963).

The soil-borne tobacco rattle virus (TRV), the causal agent of spraing and stem mottle, is carried in the seeds of some weed species. Seedlings from virus-infected seed could serve as the source from which nematode vectors obtain TRV and transmit it to healthy potato plants in the field; weeds may also be of importance in the spread to potatoes of the tomato black ring virus (CADMAN, 1963).

3. THE NEED FOR CULTIVATION AFTER PLANTING

Successful potato growing has been associated with frequent post-planting cultivations, and ALDRICH, BLAKE and CAMPBELL (1954) estimate that during a season there may be up to 25 miles of tractor travel per acre (including spraying and harvesting). SANDERS (1957), in a standard British textbook, stresses that thorough cultivation,

including deep stirring between the ridges, rolling and harrowing, are in most cases essential but advises the farmer to stay away form his field during the most drastic operation (harrowing the ridges afger emergence) in case he should be afraid for the safety of his crop.

The practice of intensive post-planting cultivation in potatoes is carried on in spite of the weight of experimental evidence against it. Writing of North American conditions nearly 30 years ago, MOORE (1937) states that there is no advantage in the cultivation of potatoes except for weed control; both PEREIRA (1941) and RUSSELL (1949) arrived at essentially the same conclusion in Britain. ALDRICH *et al.* (1954) concluded that, when weeds were controlled chemically, more than two or three post-planting cultivations reduced potato yields, and a similar conclusion was reached by EVERETT (1957b). The former authors show that cultivating relatively wet soil in the period immediately after planting causes compaction (with resultant reduction in air space) and destroys the soil particle aggregates responsible for a good tilth. However, it has sometimes been shown that a limited amount of post-planting cultivation can be beneficial (SINGH, 1956; GREEN 1962; ALDRICH and CAMPBELL, 1952; ALDRICH *et al.* 1954; EVERETT, 1957a and b, 1958b; BURGHAUSEN, 1963a). Some soils, particularly those containing a high proportion of silt or clay, easily lose their natural structure and may require more post-planting cultivation than lighter soils (SMITH, 1955; SCRAGG, 1964*a*). Silty clay soil, when deliberately packed down before planting, has been shown by BLAKE, BOELTER, ADAMS and AASE (1960) to delay shoot emergence, stunt growth, and lead to the formation of poor quality tubers near the soil surface. FLOCKER, TIMM and VOMOCIL (1960) also found that soil compaction reduced yield and quality. The potato is not a deep-rooting plant and root penetration is impeded when a plough pan is formed by normal cultivations; DE ROO and WAGGONER (1961) found that the compaction caused by spraying machine and tractor wheels was sufficient to restrict root extension. Clearly any post-planting cultivation on heavy or silty soils liable to compaction must only be done when the soil is relatively dry, as otherwise the situation may be worsened rather than improved.

A side effect of cultivating certain soils is the production of stable clods that persist in the ridges until harvest, when, because of their similarity in size and density to potato tubers, they increase hand work on mechanical harvesters (ROBERTSON, 1960a and b). Some of these clods are formed at or before planting, but the majority are formed during the post-planting cultivations by the implements used and by tractor wheels (N.I.A.E., 1958–59; SHOTTON, 1964). It has been shown by GREEN (1962a and b, 1964) that the number of clods present at lifting time can be kept to a minimum by preparing the ground for planting by rotary cultivation, or by using one of a number of specially devised implements now available. Cultivation not only destroys weeds, but stimulates further weed germination (ROBERTS, 1963; CHANCELLOR, 1964a), and according to ELLIOTT and COX (1964) can often be considered as "making a stick to beat one's own back". It has been observed that soil not recently disturbed is able to give out more heat at night than an otherwise identical disturbed soil, presumably because more heat has passed into the soil during the day. The extra heat radiation

during the night can sometimes be enough to prevent damage to emerged potato foliage during a radiation frost (ELLIOTT and BOYLE, 1963; SCRAGG, 1964a). Herbicides have been recommended in the Netherlands for use in areas particularly liable to frost in which cultivations prior to emergence would reduce the depth of soil above the tubers and so expose them to greater frost risk (VAN DER ZWEEP, 1963). During wet weather (or under irrigation) cultivation may in any case be difficult or ineffective for weed control (INGRAM, 1964).

Attention has been drawn by several authors to the spread of potato virus X by the passage of mechanical implements, and to the need for some other method of weed control in seed potatoes (HARTEL, 1961; BURGHAUSEN, 1963a; KABIERSCH, 1964; SCRAGG, 1964a). HUGHES (1964) reported that in a wet spring incidence of blackleg was reduced where post-planting cultivations were omitted.

Potatoes are usually grown in ridges, which, according to SANDERS (1957), are made to prevent greening of the tubers and to protect them from blight spores. PEREIRA (1941) gives three reasons for ridging, namely to reduce damage from sprayer wheels, to reduce greening, and to suit the present harvesting machinery. He suggests that very low ridges are sufficient to prevent greening, a conclusion supported by MOORE (1937) who found they had little advantage over planting on the flat, though varieties forming their tubers near the surface, such as *Katahdin*, are liable to greening if not adequately covered (SMITH, 1955). SHOTTON (1964) however, round that when ridges were run up at the time of planting, and subsequent weed control was by means of herbicides, then larger ridges produced higher yields and a smaller percentage of greened tubers. The depth of soil above the tubers certainly affects development as was noted by IVINS and MONTAGUE (1958), shallow covering tending to produce a larger number of smaller tubers.

4. TYPES OF WEED PROBLEM

The weediness of a potato crop is controlled by many factors including the species of weed present, weather and climate, and the speed with which the potato plants are able to produce a weed-smothering canopy of foliage. Some of these factors are considered in detail by ELLIOT and COX (1964). Rapid and uniform crop emergence depends upon cultural factors such as variety, size and quality of seed, a suitable manurial regime (RADEMACHER, 1957) and pre-treatment of the seed (HEADFORD and INGERSENT, 1961). It depends only to a very limited extent on the depth of soil covering the tubers (SHOTTON, 1964).

Three principal types of weed infestation in potato fields can be distinguished, occurring either singly or together.

4.1 Perennial weeds

Couch grass (*Agropyron repens*) and Bermuda grass (*Cynodon dactylon*), sedges (*Cyperus* spp.) creeping thistle (*Cirsium arvense*) and other perennial species thrive on the fertile light loam soils favoured for potato production, and have been recorded as major weeds of potato fields in various parts of the world.

Control of most of these species by cultivation or by chemicals is difficult once the crop has been planted, and every effort must therefore be made to deal with the problem before planting (RADEMACHER, 1957).

4.2 Annual weeds emerging before and with the crop

The main purpose of the intensive post-planting cultivations generally recommended, for example by SANDERS (1957), is to control this group of weeds. Potatoes are usually planted in warm soil in the spring, and the period of up to 3 months during which the crop offers little competition to weeds coincides with rapid weed germination and growth (ELLIOT and COX, 1964). Weeds growing from seed emerge well in advance of the crop and, if permitted, soon grow above the potatoes. As already noted, the presence even of small weed seedlings at the time of potato emergence can reduce yields.

4.3 Late germinating weeds

The cover provided by the foliage of potatoes is sufficient to suppress most weed growth, although the duration of this protection may be short (ELLIOT and COX, 1964), and some present-day varieties are unable to maintain full ground cover at any stage of growth (SAWYER and DALLYN, 1964). Where summer temperatures are high, as in parts of the United States, annual grasses thrive, particularly species of the genera *Setaria*, *Digitaria* and *Echinochloa* (WARREN, 1960). These annual grasses can be controlled for a time by cultivation, and they only become a problem after "lay-by", the North American term for the stage beyond which further post-planting cultivation is impossible (ILNICKI, CAMPBELL, TISDELL and COLLINS, 1961). Annual grasses and other weeds growing after lay-by may have little effect on yield but, as noted above, weeds at this stage can interfere with harvesting. A similar situation occurs in Germany, where the rapidly growing broad-leaved annuals *Galinsoga parviflora* and *G. quadriradiata* begin to germinate in the warmth of mid-summer at about the time of lay-by (RADEMACHER, 1957). These ephemeral species grow quickly as the crop matures and its leaf canopy opens, producing a dense tangle of weed growth by lifting time.

5. HOW HERBICIDES CAN BE USED TO CONTROL WEEDS

Herbicides are either applied directly to weed foliage or to the soil from where they exert a toxic action on weeds.

Herbicide technology has advanced rapidly since the discovery of 2,4-D and MCPA, and many types of chemical structure have been found to have selective herbicidal properties (ENNIS, 1964). An account of modern herbicides and their properties is given by WOODFORD and EVANS (1963), and their terminology is used in this review. Very few herbicides are sufficiently selective for direct application to the standing crop, but many can be applied to the weeds and soil at any time between planting and the emergence of the potato shoots. This period is of variable duration but may be as

much as 5 weeks (ELLIOTT and COX, 1964). The chemicals that have shown the most promise as herbicides in potato growing are shown in their appropriate category in the TABLE. No attempt has been made to list the weed spectra of particular herbicides, and the reader is referred to the manufacturer's literature, or to an authority such as WOODFORD and EVANS (1963). It is possible that the selectivity of some herbicides to potatoes can be increased by incorporating them with petroleum mulch as MILLER and ABRAMITIS (1962) have shown for another crop.

TABLE. Herbicides that have been used successfully in the potato crop

Time of utilization – *Zeit des Einsatzes époque d'utilisation*	Herbicides acting through – *Einwirkung der Herbizide auf – herbicides agissant par*		
	foliage *Blätterle feuillage*	the soil *Boden le sol*	foliage and soil *Blätter u. Boden feuillage et sol*
1. Pre-planting – *vor dem Auspflanzen avant la plantation*		TCA EPTC	dalapon
2. At planting – *beim Auspflanzen à la plantation*		EPTC	
3. Pre-emergence (or as first few shoots emerge) – *vor dem Auflaufen (oder wenn die ersten paar Triebe erscheinen – avant la levée (ou à la levée des premières pousses)*	2,4-D MCPA diquat paraquat solan calcium cyanamide DPA	simazine EPTC diuron monuron	linuron monolinuron prometryne dinoseb amine dinoseb acetate dinoseb acid in oil DNOC G 36393 C 3126
4. Post-emergence – *nach dem Auflaufen après la levée*	DPA 2,4-D MCPA calcium cyanamide	EPTC R 1607	

Note – *Anmerkung – nota*
All common names and abbreviations follow the list published in *Weed Research*, the official journal of the European Weed Research Council – *alle gewöhnlichen Namen und Abkürzungen sind der in der offiziellen Zeitschrift des European Weed Research Council (Europäische Rat für Unkrautsforschung)* Weed Research *(Unkrautsforschung) veröffentlichten Liste entnommen – tous les noms communs et abréviations sont conformes à la liste publiée dans* Weed Research *(Recherche sur les mauvaises herbes), le journal officiel du European Weed Research Council (Conseil de Recherches Européen sur les Mauvaises Herbes).*

G 36393 – 4-isopropylamino-6-(methoxypropylamino)-2-methylthio - 1,3,5-triazine.
C 3126 – N-(p-bromophenyl)-N'methyl-N'-methoxyurea.
DPA – N-(3,4-dichlorophenyl)propionamide.
R 1607 – propyl di-n-propylthio-carbamate.

TABELLE. *Herbizide, die im Kartoffelbau mit Erfolg angewendet werden*
TABLEAU. *Herbicides qui ont été utilisés avec succès dans la culture de la pomme de terre*

5.1 Pre-planting herbicide treatment

It has been noted above that perennial weeds can be difficult to control once the crop has been planted, and attempts have therefore been made to control couch grass and

other perennial grasses with either TCA or dalapon before planting. There are several recommendations for using dalapon (TREVETT and MURPHY, 1958, 1963; ERDMAN and MEGGITT, 1964; ISLEIB, 1960; Wisconsin College of Agriculture, 1964), but care has to be taken to avoid too high a concentration reaching the potatoes because dalapon can reduce the intensity of the colour in red varieties (NYLUND and RIES, 1958) and can affect the formation of tubers (GAUSMAN, CORBETT and STRUCHTEMEYER, 1958). It is preferable to apply dalapon the previous autumn at a higher and more effective rate particularly in the case of seed crops (Wisconsin College of Agriculture, 1964). TCA, another herbicide effective against couch grass, has been widely tested in Europe and elsewhere as a pre-planting treatment, and results have been reported by BYLTERUD (1958); Anon. (1959a); GRANSTROM, MUKULA, PETERSEN and BYLTERUD (1960), KRÜGER (1961); NEURURER (1961b) and MCLAUGHLIN (1954). Some varietal variation in response to pre-planting application of TCA has been noted and, at high rates, reduced yields recorded (BYLTERUD, 1958; GRANSTROM, 1960). Another herbicide that can be applied and mixed into the soil before planting is EPTC, used at low rates to control annual grasses, and at higher rates for control of nut grasses (*Cyperus* spp.) (ERDMAN and MEGGITT, 1964).

5.2 Herbicide application at or soon after planting

If a safe herbicide with a prolonged soil activity could be found this would be an ideal stage at which to spray because the crop could then be left (as far as weeds are concerned) until harvest. Simazine, which has a sufficiently long residual action and wide spectrum of weed control is sometimes toxic to the potato at weed-killing rates (HOLLY, 1962; MILFORD and PFEIFFER, 1962; PURNELL, MCCARTY and LITTLE, 1959; TREVETT and MURPHY, 1958; VOSSEN, 1959, 1961; PFEIFFER and PHILLIPS, 1964), particularly if herbicide application is followed by irrigation (MOFFAT, 1964).

EPTC, a soil-acting herbicide, is tolerated by the potato at this stage, and in N. America is recommended for incorporation with surface soil immediately after planting to control nut grasses (*Cyperus* spp.) (SAWYER, DALLYN and COLLIN, 1960). PRASAD, SINHA and MUKHERJEE (1960) applied 2,4-DES four days after planting, but the margin of safety with this herbicide was found to be small.

5.3 Herbicide application immediately before or soon after crop emergence

Several workers in North America including TREVETT and MURPHY (1963), ERDMAN and MEGGITT (1964), EVERETT (1957b, and 1958b), and ALDRICH *et al.* (1954) have remommended the use at this stage of particular chemicals at various rates but, as was pointed out by BAYER and SWEET (1964), the conditions of climate, soil and weed problem vary so much that any recommendations must relate to a specific local problem; the majority of the herbicides mentioned below are capable of severely reducing yield when not used in accordance with recommendations. Where annual weeds predominate, the technique generally used has been to allow the land to remain undisturbed after planting and then to spray herbicides as the first few potato shoots emerge. There is by this time a stand of young weeds and, to be successful, a herbicide

treatment must be capable of destroying these weeds completely (NEILD and PROCTOR, 1962). To provide control of weeds that germinate subsequently, some soil activity is essential and HOLLY (1962) and others have assessed the response of the potato to soil-acting herbicides. In practice, a purely foliar acting chemical such as diquat, paraquat or solan is effective only where there is little or no further weed germination following crop emergence. Better results with foliar-acting herbicides can be obtained by delaying application to ensure as full a germination of weeds as possible; destruction to ground level of the emerged potato shoots seems to do little harm but there is always some risk of foliar absorption leading to permanent damage to the plant.

For situations in which there is some weed germination after potato emergence, a combination of soil and foliar activity is required. Both types of action are shown by certain herbicides, for example linuron (TABLE). Mixtures of two or more herbicides in which the dose of each can be varied independently to suit a particular weed situation have an advantage over single herbicides (ELLIOTT and COX, 1964). When annual grasses form an appreciable proportion of the weeds, it may be necessary to include in such mixtures a grass-killing herbicide such as TCA, dalapon or paraquat though dalapon should not be used on red varieties. Dalapon applied to emerged shoots of some varieties may also cause damage (ADAMSON, 1957). Earlier work demonstrated the usefulness of dinoseb-amine, either alone or in mixtures with TCA or dalapon and, more recently, promising results have been obtained with dinoseb formulated in oil (JOICE and NORRIS, 1964), dinoseb-acetate and DNOC (VERLAAT, 1961). However, all formulations of dinoseb and DNOC are poisonous to man and animals and a less dangerous and unpleasant substitute is desirable. The soil-acting herbicides diuron and monuron can be damaging to potatoes (BELL and TISDELL, 1958; PURNELL *et al.* 1959; EVERETT, 1958a, 1963) though diuron (TREVETT and MURPHY, 1963), and monuron (NYLUND and RIES, 1958) have been recommended for certain situations. Simazine, like monuron and diuron, has a relatively narrow margin of safety, but it has been successfully used at a low rate in mixtures with prometryne as a pre-emergence herbicide (PFEIFFER and PHILLIPS, 1964), who also found mixtures of trietazine with desmetryne and trietazine with 4-isopropylamino-6-(methoxypropylamino)-2-methylthio-1,3,5-triazine promising.

Simazine occasionally causes the potato foliage to be unusually luxuriant and of a darker colour (BURGHAUSEN, 1963a); the cause of this response is unknow but may be similar to the growth stimulation of some other plants recorded by GAST and GROB (1964).

Linuron, the closely related herbicide N-(p-bromophenyl)-N-methyl-N-methoxyrea (SCHULER and EBNER, 1964), monolinuron, prometryne, diquat and paraquat have recently shown considerable promese. Many workers have reported successful results with these herbicides, used either alone or as a constituent part of mixtures (BAYER and SWEET, 1963 and 1964; BELL and REGAN, 1964; COWAN and JOY, 1964; MILNE and HYDE, 1964; PFEIFFER and PHILLIPS, 1964; SHOTTON, 1964; STEPHENS, 1964; VOSSEN, 1964; WATERSON, 1964).

EPTC or the related compound propyl di-n-propylthiocarbamate are recommended

for application just prior to emergence in N.America to land infested with nut grass (*Cyperus* spp.).

5.4 Overall post-emergence application to weeds and crop

Under European conditions the use of an effective weedkiller combining foliar and soil activity near the time of potato emergence has frequently provided adequate weed control until lifting time but, as noted above, annual grasses in N. America and *Parviflora* spp. in Germany are frequently problems after lay-by. Most of the foliar-acting herbicides already considered, including dalapon, linuron, monolinuron, prometryne, dinoseb, paraquat and diquat, will damage ptato foliage and they should not be applied as overall sprays after the crop has fully emerged. However, crop damage may be avoided by spraying between the rows with no-drift nozzles or by applying herbicides formulated as granules that roll off the leaves (HAWKINS, 1961, 1962a, b and c; RADEMACHER, 1957).

A number of herbicides, including 2,4-D, MCPA, 2,4,5-T, mecoprop, MCPB, DPA (N-(3,4-dichlorophenyl) propionamide) and solan, have been tried as overall post-emergence sprays but none have proved altogether safe in potato fields except at closely specified rates and times of application. The crop has an inherent resistance to several of the growth-regulator herbicides, particularly MCPA, which has sometimes been recommended for use at an early stage of growth (WOODFORD and EVANS, 1963; RADEMACHER, 1957; LETRIES, 1953; PERMIN and PETERSEN, 1957; Anon., 1955; HANF, 1957; MORKEN and VIDME, 1960), and also for application to weeds germinating as the foliage begins to senesce (FISCHNICH, PÄTZOLD and SCHILLER, 1958). Some varieties are damaged relatively easily and although the typical leaf distortion caused by MCPA is not necessarily associated with reduced yield, such distorted leaves may be confused with symptoms of virus disease. 2,4-D has also been widely tested but it too has been shown to have various effects on the potato such as altering the size distribution of the harvested tubers (NELSON and NYLUND, 1963), intensifying the colour of red varieties (NYLUND, 1956) and reducing yield (PÄTZOLD, 1961; AWASTHI, PUSHKARNATH and SINGH, 1960), but, as with MCPA, large differences in varietal susceptibility have been found (BERG, 1958). Trials with other growth regulators such as 2,4,5-T (PÄTZOLD, 1961), mecoprop and MCPB (Anon., 1959b), have shown that these substances also can cause damage to the potato; solan has been found to reduce yields when applied post-emergence (DINKEL, 1961). DPA has shown promise in some trials (TREVETT, MURPHY and GARDNER, 1963, 1964) although yields have sometimes been reduced (SAWYER and DALLYN, 1964).

6. SOME IMPLICATIONS OF USING HERBICIDES IN THE POTATO CROP

The present methods of preparing land for planting, the plant spacing adopted, the practice of ridging, and the techniques of harvesting, have been developed for a crop that is sensitive to weed competition and must therefore be cultivated before and after emergence until the extent of its foliage is sufficient to smother weed growth. If most

of this post-planting cultivation is rendered unnecessary through the use of herbicides then other and perhaps radically different methods can be considered. But before there can be widespread acceptance of the use of herbicides in the potato crop, it must be demonstrated beyond doubt that their use does not involve any toxic hazard to the consumer, particularly in those countries where potatoes form a large proportion of the diet.

From the evidence available it cannot be claimed that yield increases are general where the use of herbicides has replaced post-planting cultivation, but they have frequently been recorded (SCRAGG, 1964a and b; COWAN, 1964; and SHOTTON, 1964), particularly for early varieties. ECKERSALL and BREMNER (1964) suggest that yield increases are more likely when the effectiveness of weed control by cultivation is limited by wet weather. Post-planting cultivations can harm the crop by root pruning (MOORE, 1937), or perhaps cause a critical loss of soil moisture (SMITH, 1962), although the latter is considered unlikely by ECKERSALL and BREMNER (1964) in view of the self-mulching properties of soil. Reduction in yield following the application of a recommended herbicide treatment may sometimes be due to crop damage caused by the herbicide itself (SHOTTON, 1964) or to perennial weeds being more effectively controlled by cultivation than by chemicals (SCRAGG, 1964b).

The factors responsible for yield in the potato have been discussed by, among others, RADLEY, BREMNER and TAHA (1961), RADLEY (1963), IVINS (1963), PENMAN (1963), MILTHORPE (1963) and WATSON (1963), and the findings of these authors explain the comparative insignificance of post-planting cultivation as a factor in yield. The unit plant making up the population in a potato field is the individual shoot, and not the total growth of shoots from each tuber (BATES, 1935; HOLLIDAY, 1960), which partially explains the finding of BOYD and LESSELS (1954) that total yield depends, in practice, on weight rather than on numbers of seed planted. Experiences with other row crops suggested that changes in spatial arrangement that permitted higher planting densities per acre without overcrowding in the rows might lead to greater yield of tubers (BLEASDALE, 1963a and b); but when they tested a wide range of spacings, ECKERSALL and BREMNER (1964) found no yield increase under their conditions.

A system of bed culture has been widely tested, with normally three, but sometimes more, rows occupying a flat topped bed straddled by tractor and implements. No outstanding advantage over single rows has yet been demonstrated for this system when the same planting density per acre has been used (SHOTTON, 1964; GREEN, 1964). Denser planting in beds soon caused overcrowding, according to GREEN (1962a), who found that each tuber required a ground area of at least 550 in^2/ (3550 cm^2/) for optimum growth. Row widths of up to 36 in (91,5 cm) are the normal practice in the United States and they offer the advantages of a shorter distance of row per acre to plant, spray and harvest, but results in Britain have shown no other clear advantage over the usual 28 in (71 cm) spacing.

7. RESIDUES, OFF-FLAVOURS AND EFFECTS ON SEED TUBERS

There is as yet little published information on residue levels in potato tubers following

the use of herbicides. Methods of analysis in current use are capable of detecting residues of some herbicides at levels of about 0,1–0,05 p.p.m. (OLNEY, BELL and KERR, 1962; KERR, BELL and MANNING, 1963; GUTENMAN and LISK,1960). According to MANNING, BELL, KERR and SHUTAK (1963), the limit of sensitivity of whose tests for linuron in potato tubers was 0,02 p.p.m., detectable residues were found in the tubers when this compound was applied either late or at twice the normal rate. Several workers have observed the effect of herbicides on the quality and storage of potatoes. EASTWOOD (1952) and EASTWOOD and COBB (1954, 1956) report changes in specific gravity, but they found no consistent results from year to year, and no change in the levels of reducing sugars that could be attributed to herbicide treatment. PALFREY (1960, 1961) reports that a number of herbicides, including dalapon, dinoseb, diuron, simazine and MCPA had no effect on cooking quality, total solids, or, after winter storage on sprouting. SAWYER, DALLYN and COLLIN (1958), however, found that both dalapon and diuron applied during the growing season increased shrinkage during storage and, according to BURGHAUSEN (1963b) an excessive dose of simazine reduced the starch content of the tubers.

No strong off-flavours have been ascribed to herbicides, though it is known that the potato readily picks up insecticide taint from soil residues (GYRISCO, MUKA and BRIANT, 1959; KIRKPATRICK, LINTON, MOUNTJOY and ALBRIGHT, 1955). The latter showed that development of off-flavours depends on soil type, weather and other factors.

In several countries, manufacturers who intend to market pesticide chemicals are required to submit data to the government on the residue levels to be expected in the field, and on the inherent toxicity of their product. It is to be hoped that such data will eventually be published. The regulations may be voluntary, as in Britain; or compulsory, as in the United States, but the intention of the schemes in use in each country is to protect the public from pesticide-contaminated food. HÄRTEL (1964) for example, states that in the United States the maximum level of linuron residue permitted in ware potato tubers is 1,0 p.p.m., a level that can be detected easily by chemical analysis. Chemical residues are obviously of particular importance in the potato crop, which sometimes forms a large proportion of the total diet. Certain herbicides have already been approved for use in the potato crop in some countries, but reference should always be made to local official recommendations and regulations.

8. CONCLUSIONS

Chemical weed control in potatoes is already commercial practice in some parts of the United States and it is being rapidly developed in Britain and other countries in Northern Europe. Precise recommendations must be worked out to suit local requirements because the climate, soils, varieties, type of weed problem encountered and other factors vary so widely between different regions. Nevertheless it is likely that even if chemical methods are little cheaper than traditional methods of cultivation, they will eventually become widely adopted because of the other advantages the system offers. Excessive cultivation of potatoes has often been shown to be directly harmful

to the crop, although a limited amount has sometimes been beneficial. Other undesirable side effects of cultivation have been demonstrated such as formation of stable soil clods, spread of virus disease, and reduced protection from radiation frosts.

It is evident from the conflicting results of experimental work that our understanding of the factors responsible for yield in the potato is still too restricted to enable the farmer to make full use of the freedom in planting arrangement that the use of herbicides confers. But it is reasonable to hope that with precise control of seed pretreatment, seed size, planting depth and spacing, and with irrigation available, it should be possible to produce a high proportion of the size of tuber that is required, whether it be a small size for seed or a medium size for pre-packing.

ZUSAMMENFASSUNG

DIE STELLUNG DER HERBIZIDE IM KARTOFFELBAU

Wichtigste Aufgabe der Bodenbearbeitung nach dem Auspflanzen ist die Bekämpfung der Unkräuter; sie ist für die Kartoffel von geringem direktem Nutzen. Obwohl die Erträge in Versuchen oft durch übertriebene Bodenbearbeitung vermindert wurden, bleibt der weitverbreitete Glaube bestehen, dass Kartoffeln nicht ohne häufige und gründliche Bodenbearbeitung erfolgreich angebaut werden können.

Bodenbearbeitung nach dem Auspflanzen bewirkt vorübergehend eine Bekämpfung des Unkrauts, hat aber den Nachteil, die weitere Keimung von Unkraut zu fördern, das Kartoffelvirus X auszubreiten und zähe Erdklumpen zu bilden, die bei der mechanisierten Ernte störend wirken; ferner dürfte unter gewissen Umständen der gelockerte Boden weniger Wärme abgeben, was die Möglichkeit von Schäden durch Ausstrahlungsfroste am Blattwerk erhöht. Ein weiterer Nachteil aller Formen mechanischer Reihenbearbeitung liegt in der Beschränkung, die sie der räumlichen Anordnung der Pflanzen im Feld auferlegt.

Die Kartoffel erträgt die Konkurrenz des Unkrautes nicht gut. Wenn Herbizide die mechanische Bodenbearbeitung als Unkrautbekämpfungsmethode ersetzet sollen, müssen sie wirksam sein und keine schädlichen Rückstände in den Knollen hinterlassen. Herbizide variieren in ihren Wirkungen auf die Kartoffel, und in kleinerem Ausmass reagieren auch die Kartoffelsorten unterschiedlich.

Verschiedene Herbizide sind nun zur Anwendung vor dem Auflaufen der Pflanzen empfohlen worden, nämlich Paraquat, Dinoseb, Linuron, Monolinuron und Prometryn. Nach dem Auflaufen werden die Pflanzen leichter durch Herbizide geschädigt, und obwohl 2,4-D und MCPA in begrenztem Umfang angewendet wurden, wird keines dieser Mittel sehr empfohlen. Behandlung mit Dalapon oder TCA vor dem Auspflanzen wird ebenfalls praktiziert, wenn das Grundstück mit Quecken (*Agropyron repens*) stark verunkrautet ist. Die häufig gebrauchten Herbizide im Kartoffelbau sind in der TABELLE zusammengestellt. Offizielle Empfehlungen für die Anwendung von Herbiziden vor den Auspflanzen und vor dem Auflaufen basieren auf lokalen Bedingungen, und weder ein allgemein zuverlässig wirksames, einzelnes Herbizid, noch eine Mischung von Herbiziden hat Aussicht, bei der Vielfalt der Wachstumsbedingungen und der Unkrautprobleme in der Praxis erfolgreich zu sein.

Wenn die Zahl der Bearbeitungsgänge durch das Kartoffelfeld nach dem Auspflanzen durch die Anwendung von Herbiziden vermindert werden kann, werden sich zwei unmittelbare Vorteile ergeben. Erstens wird die Ausbreitung des Kartoffelvirus X eingeschränkt und zweitens wird die Erdklumpenbildung fast ganz verhütet. Wenn die Erdklumpenbildung verhütet werden könnte, würde dies die vollmechanisierte Ernte auf schwereren Böden sehr erleichtern. Die jetzt gebräuchlichen Reihenabstände könnten radikal geändert werden, wenn die mechanische Bodenbearbeitung nach dem Auspflanzen sich erübrigen würde, doch hat sich aus den untersuchten, alternierenden Versuchsverfahren noch kein anhaltender Vorteil ergeben.

THE PLACE OF HERBICIDES IN THE POTATO CROP

RÉSUMÉ

LA PLACE DES HERBICIDES DANS LA CULTURE DE LA POMME DE TERRE

Nous avons montré que la fonction première de l'ameublissement du sol après la plantation était de détruire les mauvaises herbes; cet ameublissement a peu d'avantage direct pour la récolte. Bien que les expériences ont montré qu'un travail excessif du sol réduit souvent les rendements, l'opinion est largement répandue selon laquelle les pommes de terre ne peuvent donner un plein rendement sans de fréquents et complets ameublissements du sol.

Le travail du sol après plantation réalise une destruction temporaire des mauvaises herbes mais il apporte aussi les désavantages de favoriser la germination de nouvelles mauvaises herbes, de propager le virus X de la pomme de terre et de former des mottes de terre dures qui contrarient la récolte mécanique; en outre, un sol dérangé peut, sous certaines circonstances, rayonner moins de chaleur durent les gelées par rayonnement accroissant ainsi les chances de dommages du froid au feuillage. Un inconvénient supplémentaire de toutes les formes de travail du sol entre les lignes est qu'il limite les dispositions spatiales des plantes dans le champ.

La pomme de terre est très susceptible à la compétition des mauvaises herbes. Si les herbicides doivent, en tant que méthode de destruction des plantes nuisibles, remplacer le travail du sol, ils doivent être efficaces et ne laisser aucun résidu nuisible dans les tubercules. Les herbicides ont des effets variables sur la pomme de terre, et, à un degré moindre, les variétés diffèrent dans leur réaction.

Actuellement plusieurs herbicides ont été recommandés pour l'utilisation avant la levée, notamment les paraquat, dinoseb, linuron, monolinuron et prométryne. Apès la levée, la culture est plus facilement endommagée par les herbicides et, bien que le 2,4-D et le MCPA aient été utilisés dans une mesure limitée, aucun n'est largement recommandé. Le traitement avant la plantation avec le dalapon ou le TCA est également pratiqué là où le chiendent (*Agropyron repens*) infeste le sol. Dans le TABLEAU figurent les herbicides communément utilisés dans la culture de la pomme de terre. Les recommendations officielles pour l'utilisation d'herbicides avant la plantation et avant la levée sont basées sur les conditions locales et aucun herbicide simple ou mélange d'herbicides ne peut être universellement utilisé avec pleine efficacité et en toute sécurité dans les nombreuses conditions de croissance et pour tous les problèmes de mauvaises herbes rencontrés dans le pratique.

Deux avantages immédiats résulteront de la réduction de la circulation dans le champ après plantation grâce à l'utilisation des herbicides: d'abord l'extension du virus X peut être réduite et, ensuite, la formation de mottes de terre est presque totalement empêchée. Si l'absence de mottes pouvait être assurée, l'arrachage complètement mécanique dans les sols lourds serait grandement facilité. Les espacements entre les lignes en usage présentement pourraient être radicalement changés si le travail du sol après la plantation n'était pas plus longtemps requis, mais les divers espacements qui ont été expérimentés n'ont pas encore révélé de valeur certaine.

REFERENCES

ADAMSON, R. M. (1957): Horticultural crops and sugar beet. *Res. Rep. Nat. Weed Comm. W. Sect.* 101–118.

ALDRICH, R. J., G. R. BLAKE and J. C. CAMPBELL (1954): Cultivation and chemical weed control in potatoes. *Circ. New Jers. Agric. Expt. Stn.* 557.

ALDRICH, R. J., and J. C. CAMPBELL (1952): Effect of weeds, cultivations and pre-emergence herbicides on potato and corn yields. *Proc. 6th NEast Weed Control Conf.* 199–207.

ANDERSON, E. G. (1958): Trends in weed control. *Rep. Quebec Soc. Plant Prot.* 46–58.

Anon. (1955): Sprojtning med hormonpraeparater i kartofler. *Tidsskr. Planteavl.* **59,** 727–728.

——— (1959a): Resultater av nordiske fellesplaner for bekiempelse av kveke. *Nord. JordbrForsk.* 1960, Suppl. 1, 132–138.

——— (1959b): Potatoes. *Res. exp. Rec. Min. Agric. N. Ire.* **9,** 282.

AWASTHI, O. P., PUSHKARNATH and M. SINGH (1960): Effect of pre-emergence treatment with 2,4-dichlorophnoxy acetic acid on weeds in potato crops. *Indian Potato J.* **2**, 104–107.

BATES, G. H. (1935): A study of the factors influencing size of potato tubers. *J. Agric. Sci.* **25**, 297–313.

BAYER, G. H., and R. D. SWEET, (1963): Potato response to linuron and Hercules 7531 at four stages of growth on muck and mineral soils. *Proc. 17th NEast Weed Control Conf.* 158–161.

BAYER, G. H., and R. D. SWEET (1964): Potato herbicides: a summary of their performance under three years of field testing. *Proc. 18th NEast. Weed Control Conf.* 159–165.

BECKER, G. (1962): Unkraut- und Bearbeitungseinfluss bei der Kartoffelpflege. *Z. Acker- u. PflBau.* **115**, 177–185.

BELL, R. S., and J. B. REGAN (1964): Weed control in Kennebec potatoes. *Proc. 18th NEast. Weed Control Conf.* 153–158.

BELL, R. S., and T. F. TISDELL (1958): Pre-emergent and post-tilling weed control tests with potatoes. *Proc. 12th NEast. Weed Control Conf.* 61–65.

BERG, F. (1958): Beobachtungen über die Anwendung selektiver Wuchsstoffe zu Kartoffeln nach dem Schliessen des Bestandes. *Dt. Landwirt. Berl.* **9**, 333–334.

BLAKE, G. R., D. H. BOELTER, E. P. ADAMS and J. K. AASE (1960): Soil compaction and potato growth *Am. Potato J.* **37**, 409–413.

BLEASDALE, J. K. A. (1963a): Crop spacing and management under weed-free conditions. *2nd Symp. of Br. Weed Control Council.* 90–101.

——— (1963b). *Rep. Nat. Veg. Res. Sta.* 41–42.

BOYD, D. A., and W. J. LESSELS (1954): The effect of seed rate on the yield of potatoes. *J. Agric. Sci.* **44**, 465–476.

BYLTERUD, A. (1958): Resultater av TCA – behandling mot kveke i praksis. *Samvirke.* **6**, 7.

BURGHAUSEN, R. (1963a): Chemische Unkrautbekämpfung in Kartoffeln. (1 Vorauflaufbehandlung). *Dt. Landwirt. Berl.* **14**, 230–233.

——— (1963b): Unkrautbekämpfungsversuche mit Triazinderivaten im Kartoffelbau. *Albrecht-Thaer-Arch.* **7** (**7/8**), 645–666.

CADMAN, C. H. (1963): Biology of soil-borne viruses. *A. Rev. Phytopath.* **1**, 143–171.

CHANCELLOR, R. J. (1964a): Emergence of weed seedlings in the field and the effects of different frequencies of cultivation. *Proc. 7th Br. Weed Control Conf.* 599–606.

——— (1964b): The depth of weed seed germination in the field. *Proc. 7th Br. Weed Control Conf.* 607–613.

COWAN, W. T., and N. B. JOY (1964): The use of Linuron for the control of annual weeds in potatoes. *Proc. 7th Br. Weed Control Conf.* 430–440.

DE ROO, H. C., and P. E. WAGGONER (1961): Root development of potatoes. *Agron. J.* **53**, 15–17.

DINKEL, D. H. (1961): Chemical weed control in potatoes grown in Kali silt loam soil. *Res. Rep. 18th N.cent Weed Control Conf.* 72.

EASTWOOD, T. (1952): The effect of herbicides upon potatoes used for chipping. *Am. Potato J.* **29**, 160–164.

——— and J. S. COBB (1954): The effect of herbicides upon potatoes used for chipping. *Proc. 8th NEast Weed Control Conf.* 167–175.

——— and J. S. COBB (1956): The effect of herbicides upon potatoes used for chipping. *Proc. 10th NEast. Weed Control Conf.* 93–101.

ECKERSALL, R. N., and P. M. BREMNER (1964): Some implications of the use of herbicides in the potato crop. *Proc. 7th Br. Weed Control Conf.* 487–493.

ELLIOTT, J. G., and P. J. BOYLE (1963): Crop situations where cultivations for weed control may be eliminated by use of herbicides. A. Agriculture. *From 2nd Symp. of Br. Weed Control Council.* 4–13.

ELLIOTT, J. G., and T. I. COX (1964): Potatoes free of weeds. *Proc. 7th Br. Weed Control Conf.* 401–410

ENNIS Jr., W. B. (1964): Selective toxicity in herbicides. *Weed Res.* **4**, 93–104.

——— W. C. SHAW, L. L. DANIELSON, D. L. KLINGMAN and F. L. TIMMONS (1963): Impact of chemical weed control on farm management practices. *Adv. Agron.* **15**, 161–210.

ERDMANN, M. H., and W. F. MEGGITT (1964): Weed control in field crops. *Ext. Bull.* E-434 Mich. State Univ.

EVERETT, C. F. (1957a): Potatoes. *Res. Rep. E. Sect. Nat. Weed Comm. Canada.* 14–19.

——— (1957b): Weed control practices in potatoes. *Proc. 11th Meet. E. Sect. Nat. Weed Comm. Canada.* 13–15.

——— (1958a): Potatoes. *Res. Rep. E. Sect. Nat. Weed Comm. Canada.* 17–23.

——— (1958b): Use of herbicides in the control of weeds in potatoes in the Atlantic Provinces. *Proc. 5th Ann. Pest. Tech. Soc.* 50–53.

——— (1963): Control of annual weeds in potatoes. *Proc. 17th NEast. Weed Control Conf.* 133–138.

FISCHNICH, O., C. PÄTZOLD and C. SCHILLER (1958): Wachstumsregulatoren im Kartoffelbau. *Eur. Potato J.* **1,** 1: 25–30.

FLOCKER, W. J., H. TIMM and J. A. VOMOCIL (1960): Effect of soil compaction on tomato and potato yields. *Agron. J.* **52,** 345–348.

GAST, A., and J. GROB (1964): Triazines in top fruit and viticulture. *Proc. 7th Br. Weed Control Conf.* 217–226.

GAUSMAN, H. W., E. G. CORBETT and R. A. STRUCHTEMEYER (1958): Effects of certain growth substances on number of potato tubers. *Am. Potato J.* **35,** 742–746.

GRANSTROM, B., J. MUKULA, H. I. PETERSEN and A. BYLTERUD (1960): Resultater av nordiske fellesplaner for bekjempelse av kveke. *Nord. JordbrForsk.* 132–138.

GREEN, H. C. (1962a): Row widths and inter-row cultivation of potatoes. *Eur. Potato J.* **5,** 57–67.

——— (1962*b*): An experiment on the rotary inter-row cultivation of potatoes. *J. Agric. Engng. Res.* **7,** 204–207.

——— (1964): Beds, row width, cultivation and weed control in potatoes. *Proc. 7th Br. Weed Control Conf.* 504–511.

GREIG, J. K., and A. S. AP-TIKRITI (1962): Weed control in Irish potatoes. *Proc. 19th N. cent. Weed Control Conf.* 40–44.

GUTENMANN, W. H., and D. J. LISK (1960): Improved extraction procedure for the determination of EPTC residues in potatoes. *J. Agric. Fd Chem.* **8,** 216–217.

GYRISCO, G. C., A. A. MUKA and A. M. BRIANT (1959): Studies of flowers and odours of potatoes and red kidney beans grown in rotation with lindane-treated red clover. *J. Econ. Ent.* **52,** 473-475.

HANF, M. (1957); Experiences with weed control in potatoes by growth regulators. *Mitt. biol. Zentralanst. Berl.*, 59–61.

HÄRTEL, K. (1961): Lohnt der Einsatz von Herbiziden zur Verhütung der Frühverunkrautung im Kartoffelbau. Paper read at *4th Dtsche. Arbeitsbesprechung über Fragen der Unkrautbiologie.*

——— (1964): Status and prospects of weed control with methoxyurea compounds in potato growing taking into consideration the residue problem. *Proc. 7th Br. Weed Control Conf.* 441–449.

HAWKINS, A. (1961): Post-hill chemical weed control in potatoes with granular formulations. *Proc. 15th NEast. Weed Control Conf.* 180–181.

——— (1962a): Adapting equipment for applying chemical for lay-by weed control in potatoes. *Am. Potato J.* **39,** 162–165.

——— (1962b): Use of granular applicator for lay-by weed control in potatoes. *Proc. 16th NEast. Weed Control Conf.* 165.

——— (1962c): Lay-by chemical weed control in potatoes with granular formulations by CDAA, dalapon and other chemicals. *Proc. 16th NEast. Weed Control Conf.* 178–180.

HIELE, F. J. H. VAN (1952): Onkruidschade bij aardappelen in verband met het groeistadium. *Maandbl. Landb. voorl. Dienst.* **9,** 20–27.

HOLLIDAY, R. (1960): Plant population and crop yield. Part I & II. *Fld. Crop Abstr.* **13,** 159–167 and 247–254.

HOLLY, K. (1962): The response of the potato to a range of soil-acting herbicides. *Proc. 6th Br. Weed Control Conf.* 691–696.

HUGHES, R. G. (1964): Plant population and crop density in relation to the use of herbicides in potatoes. *Proc. 7th Br. Weed Control Conf.* 512–519.

ILNICKI, R. D., J. C. CAMPBELL, T. F. TISDELL and H. A. COLLINS (1961): Problem of annual grasses after last cultivation. *Proc. 15th NEast. Weed Control Conf.* 55.

INGRAM, J. M. (1964): Weed control in potatoes – experiences in Northern Ireland 1963. *Proc. 7th Br. Weed Control Conf.* 483–486.

ISLEIB, D. R. (1960): Quackgrass control in potato production. *Weeds.* **8,** 631–635.

IVINS, J. D. (1963): Agronomic management of the potato. *Proc. 10th Easter Sch. Agric. Sci. Univ. Nott.* 303–312.

——— and V. J. MONTAGUE (1958): Note on the influence of depth of soil covering the parent tuber on the development and yield of the potato plant. *Emp. J. Exp. Agric.* **26,** 34–36.

JOICE, R., and J. NORRIS (1964): Evaluation of a dinoseb emulsifiable oil formulation for pre-emergence weed control in potatoes. *Proc. 7th Br. Weed Control Conf.* 423–429.

KABIERSCH, W. (1964): Chemical weed control in potatoes in the seed production area of Hanover. *Proc. 7th Br. Weed Control Conf.* 544–545.

KAWATEI, K., S. KITANO and Y. SHIRASAWA (1958): Studies on establishment of a weeding system in field cultivation. I. Influence of weeds on the yield of potato of non-hilling culture. *Proc. Crop. Sci. Soc. Japan.* **27,** 252–254.

KERR, T. W., R. S. BELL and P. B. MANNING (1963): Residue analysis of potatoes treated with prometryne for weed control. *Proc. 17th NEast. Weed Control Conf.* 231–232.

KIRKPATRICK, M. E., G. S. LINTON, B. M. MOUNTJOY and L. C. ALBRIGHT (1955): Flavour of sebago potatoes grown in soil treated with chlordan, heptachlor, dieldrin, aldrin, or endrin. *J. Agric. Fd. Chem.* **3,** 409.

KRÜGER, H. (1961): Beitrag zur Queckenbekämpfung im Kartoffelbau mit Natriumtrichloracetat. Paper read at *4. Dtsche. Arbeitsbesprechung über Fragen der Unkrautbiologie u. be-kämpfung.*

LETRIES, A. (1953): Ars melding for 1952. Hvoen Forsøks-og Stamsaedgard for pototer. p. 63 Forsøk med ugrassprøyting i pototer.

MANNING, P. B., R. S. BELL, T. W. KERR and V. G. SHUTAK (1963): Residues for linuron in blueberries and potatoes following treatment for weed control. *Proc. 17th NEast. Weed Control Conf.* 229–230.

MARTIN, P., and B. RADEMACHER (1960): Untersuchungen zur Frage der Wurzelallelopathie von Kulturpflanzen und Unkräutern. *Beitr. Biol. Pfl.* **35,** 214–237.

MILFORD, G. F., and R. K. PFEIFFER (1962): Preliminary assessments of triazines for weed control in potatoes from pot experiments. *Proc. 6th Br. Weed Control Conf.* 681–689.

MILLER, R. A., and W. W. ABRAMITIS (1962): Placement selectivity of amiben by the use of petroleum mulch. *Proc. 19th N.cent. Weed Control Conf.* 23.

MOFFAT, J. R. (1964): Weed control by herbicides in potatoes. *Proc. 7th Br. Weed Control Conf.* 524–535.

MORKEN, O., and T. VIDME (1960): Forsøk med kjimiske midler mot ugras i potetaker 1950-1956. *Forsk. Fors. Landbr.* **11,** 459–482.

MOORE, G. C. (1937): Soil and plant response to certain methods of plant cultivation. *Bull. Cornell Univ. Agric. Expt. Stn.* 662.

MCLAUGHLIN, J. J. A. (1954): Weed control – root crops. *Proc. 7th N. Z. Weed Control Conf.* 37–41.

NATION, H. A. (1961): Dalapon for late season grass control in potatoes. *Proc. 14th Sth. Weed Conf.* 132–140.

NEILD, R. R. A., and J. M. PROCTOR (1962): Chemical weed control in potatoes. *Proc. 6th Br. Weed Control Conf.* 697-791.

NELSON, D. C., and R. E. NYLUND (1963): Influence of 2,4-D on uniformity. *Am. Potalo J.* **40,** 391–395.

NEURURER, H. (1961a): Die Nachwirkung von Unkrautmitteln muss in der Fruchtfolge berücksichtigt werden. *Pflanzenarzt.* **14,** 33–35.

——— (1961b): Wo liegen noch Ertragsreserven. *Pflanzenarzt.* **13,** 110–112.

N.I.A.E. (1958–59): Anon. *Rep. Nat. Inst. Agric. Engng. Silsoe.* 80.

NYLUND, R. E. (1956): The use of 2,4-D to intensify the skin colour of Pontiac potatoes. *Am. Potato J* **33,** 145–154.

NYLUND, R. E., and S. K. RIES (1958): Weed control in horticultural crops. Vegetables. Res. Summ. from *15th N.cent. Weed Control Conf.* 67.

OLNEY, C. E., R. S. BELL and T. W. KERR (1962): Residue analysis of potatoes treated with trietazine for weed control. *Proc. 16th NEast. Weed Control Conf.* 189.

PALFREY, G. D. (1961): Potatoes. *Res. Rep. E. Sect. Nat. Weed. Cttee. Canada.* 6–15.

——— (1960): Potatoes. *Res. Rep. E. Sect. Nat. Weed Cttee. Canada.* 5–8.

PÄTZOLD, C. (1959): Chemische Unkrautbekämpfung im Kartoffeln? *Dt. Landwirt.* **82,** 246–247.

——— (1961): Bekämpfung von Spätunkräutern in Kartoffeln mit Wuchsstoffen. Paper read at *4. Dtsche Arbeitsbesprechung über Fragen der Unkrautbiologie u. -bekämpfung.*

——— (1964): Investigations on chemical weed control in potatoes in West Germany. *Proc. 7th Br. Weed Control Conf.* 546–547.

PAYNE, M. G., and J. L. FULTS (1955): The effects of maleic hydrazide and 2,4-D on reducing sugars and sucrose of Red Maclure potatoes. *Am. Potato J.* **32,** 144–149.

PENMAN, H. L. (1963): Weather and water on the growth of potatoes. *Proc. 10th Easter Sch. Agric. Sci. Univ. Nott.* 191–198.

PEREIRA, H. C. (1941): Studies in soil cultivation. IX. The effect of inter-row tillage on the yield of potatoes. *J. Agric. Sci.* **31,** 212–231.

PERMIN, O., and H. I. PETERSEN (1957): Forsøg med ukrudtsbekaempelse i kartofler. *Tidsskr. Planteavl.* **61,** 638–666.

PFEIFFER, R. K., and J. D. PHILLIPS (1964): Experimental work on the use of triazines for weed control in potatoes in England. *Proc. 7th Br. Weed Control Conf.* 411–422.

PRASAD, L. K., C. P. SINHA and S. K. MUKHERJEE (1960): Preliminary studies in weed control in Rabi potato grown in river sand by Crag herbicide I. *Sci. and Cult.* **25,** 688–690.

PURNELL, D. C., C. D. MCCARTY and T. M. LITTLE (1959): Herbicides on white potatoes. *Calif. Agric.* **13,** 10, 15.

RADEMACHER, B. (1957): Die Unkrautbekämpfung im Kartoffelbau. *Dt. Landwirt. Berl.* **8,** 63–67.

RADLEY, R. W. (1963): The effect of season on growth and development of the potato. *Proc. 10th Easter Sch. Agric. Sci. Univ. Nott.* 211–220.

——— M. A. TAHA and P. M. BREMNER (1961): Tuber bulking in the potato crop. *Nature, Lond.* **191,** 782–783.

RAHN, E. M., and W. F. DONALLEY (1961): Eptam for nut grass control in potatoes. *Proc. 14th NEast. Weed Control Conf.* 54.

RAKE, L., L. HOLM and M. GROSKOPP (1963): Weed control in potatoes before and at emergence. *Proc. 20th N.cent. Weed Control Conf.* 95–96.

RENNEY, A. J. (1960): Basic Studies. (Summary). *Res. Rep. W. Sect. Nat. Weed Cttee. Canada.* 116–120.

RIES, S. K., H. K. BELL, H. DAVIDSON and R. P. LARSEN (1963): Chemical weed control for horticultural crops. *Mich. St. Univ. Extension Folder F* 241.

Rijkslandbouwhogeschool, Gent (1959): Effect of growth-substance herbicides on potatoes. *Beknopt Versl. Centr. Onkruidonderz. Gent.* 15.

——— (1960): Grass herbicides before potato planting. Pre-emergence treatment of potatoes with various herbicides. *Beknopt Versl. Centr. Onkruidonderz. Gent.* 35–37.

——— (1961): Potatoes and fodder beet. *Beknopt Versl. Centr. Onkruidonderz. Gent.* 28–38.

ROBERTS, H. A. (1963): Studies on the weeds of vegetable crops. *J. Ecol.* **51,** 323–332.

ROBERTSON, I. M. (1960a): The use of herbicidal sprays on the potato crop. *Proc. 5th Br. Weed Control Conf.* 55–57.

——— (1960b): The use of herbicidal sprays on the potato crop. *J. Agric. Engng Res.* **5,** 117.

RUSSELL, E. W. (1949): The relation between soil cultivation and crop yields. *Rep. Rothamst. Exp. Sta.* 130–147.

SANDERS, H. G. (1957): An outline of British crop husbandry. Cambr. Univ. Press., p. 120 and pp. 256–258.

SAWYER, R. L., S. L. DALLYN and G. COLLIN (1958): Progress report on tolerance of potatoes to herbicides applied at last cultivation. *Proc. 12th NEast. Weed Control Conf.* 71–73.

SAWYER, R. L., G. H. COLLIN and W. H. THORNE (1959): Progress report on lay-by weed control of potatoes. *Proc. 13th NEast. Weed Control Conf.* 523–524.

SAWYER, R. L., S. L. DALLYN and G. H. COLLIN (1960): Eptam for nut grass control in potatoes. *Proc. 14th NEast Weed Control Conf.* 111–112.

SAWYER, R. L., S. L. DALLYN, G. H. COLLIN and W. H. THORNE (1960): Lay-by weed control in potatoes. *Proc. 14th NEast. Weed Control Conf.* 129–130.

SAWYER, R. L., and S. L. DALLYN (1963): Lay-by weed control in potatoes. *Proc. 17th NEast. Weed Control Conf.* 162–164.

SAWYER, R. L., and S. L. DALLYN (1964): Control of late germinating weeds in potatoes. *Proc. 18th NEast. Weed Control Conf.* 166–167.

SCHMIDT, O. (1961): Zur Bekämpfung des Franzosenkrautes in Rüben und Kartoffeln mit Simazin. *4. Dtsche Arbeitsbesprechung über Fragen der Unkrautbiologie u. -bekämpfung Hohenheim.* pp. 3.

SCHULER, J., and L. EBNER, (1964): C. 3126 – a new urea derivative herbicide in potatoes. *Proc. 7th Br. Weed Control Conf.* 450–460.

SCHULZ, H. (1961): Zur Unkrautbekämpfung in Hackfrüchten mit Kalkstickstoff. 4. *Dtsche Arbeitsbesprechung über Fragen der Unkrautbiologie u. -bekämpfung Hohenheim.* pp. 7.

SCRAGG, E. B. (1964a): Yield response to chemical weed control in potatoes. *Proc. 7th Br. Weed Control Conf.* 468–474.

——— (1964b): Chemical weed control in potatoes. *Scot. Agric.* **44**, 99–103.

SEXSMITH, J. J. (1960): Use of barban for wild oat control in a variety of crops. *Res. Rep. 17th N.cent. Weed Control Conf.* 100.

SHAW, K. (1962): Loss of mineral nitrogen from soil. *J. Agric. Sci.* **58**, 145–151.

SHOTTON, F. E. (1964): Investigations into the use of herbicides in potato crops on experimental husbandry farms. *Proc. 7th Br. Weed Control Conf.* 494–503.

SINGH, R. R. (1956): Cultural practices affecting the growth, yield and quality of main crop potatoes. Ph. D. thesis Durham Univ.

SMITH, O. (1955): Weed control and cultivation. From Potato Production in New York State. *Cornell Ext. Bull.* No. 890, p. 72, pp. 28–30.

SMITH, N. (1962): Let's have traffic congestion in the potato field. *Fm. Mechaniz.* **14**, 137–138.

STEPHENS, R. J. (1962): The control of weeds in potatoes by pre-emergence application of herbicides. *Weed Res.* **2**, 185–191.

——— (1964): Herbicide trials with potatoes at Mylnefield 1963–64. *Proc. 7th Br. Weed Control Conf.* 475–482.

STRYCKERS, J. (1960–61): Chemische onkruidbestrijding is thans ook mogelijk in groenteteelten. *Land- en Tuinb.jaarb.* 315–324.

SWEET, R. D., J. C. CIALONE and R. HARGAN (1962): Chemicals for weeding potatoes on muck and upland soils. *Proc. 16th NEast. Weed Control Conf.* 173–177.

TAYLOR, C. E. (1953): The vegetative development of the potato plant. *Ann. Appl. biol.* **40**, 778–788.

——— and N. MCDERMOTT (1959): The influence of pre-planting treatment of tubers on the growth and yield of two varieties of potato. *Eur. Potato J.* **2**, 272–277.

Tasmania (1958): Weed control. Recent developments. *Tasm. J. Agric.* **29**, 258–261.

TREVETT, M. F., C. E. CUNNINGHAM and H. J. MURPHY (1958): The effect of several herbicides on potato yields, 1954–1957. *Proc. 12th NEast. Weed Control Conf.* 390–397.

TREVETT, M. F., and H. J. MURPHY (1958): Grass control in potato fields. *Me Fm Res.* 33–35.

TREVETT, M. F., and H. J. MURPHY (1963): 1963 chemical weed killers. *Misc. Publication.* 656.

TREVETT, M. F., H. J. MURPHY and W. GARDNER (1963): Pre-emergence weed control in potatoes. *Proc. 17th NEast. Weed Control Conf.* 145–152.

TREVETT, M. F., H. J. MURPHY and W. GARDNER (1964): Annual Weed control in potatoes following planting and pre-emergence treatments. *Proc. 18th NEast. Weed Control Conf.*, 170–177.

VERLAAT, J. G. (1961): Chemische onkruidbestrijding in de vollegronds groenteteelt. *Meded. Proefsta. Groenteteelt Volle Grond*, **18**, 80.

VOSSEN, T. (1959): Onkruidbestrijding met simazin. *Rijkslandbouwconsulentschap Noord Limburg.*

VOSSEN, (1961): Ervaringen met simazin in het Rijkslandbouwconsulentschap Horst. *Tijdschr. Pl. ziekten* **67**, 66.

——— (1964): Onkruidbestrijding in aardappelen. *Landb.voorl.* **21**, 95–103.

WARREN, G. F. (1960): Use of pre-emergence herbicides for vegetables in the United States. *Proc. 5th Br. Weed Control Conf.* 413–417.

WATERSON, H. A. (1964): West of Scotland trials of potato herbicides 1961–64. *Proc. 7th Br. Weed Control Conf.* 461–467.

WATSON, D. J. (1963): Some features of crop nutrition. *Proc. 10th Easter Sch. Agric. Sci. Univ. Nott.* 233–247.

WILLIS, D. (1964): The influence of chemical weeding on the growth and yield of the potato. *Proc. 7th Br. Weed Control Conf.* 536–539.

WINDEN, W. P. VAN (1956): De stand van de chemische onkruidbestrijding bij enkele groentegewassen. *Jaarversl. Naaldwijk Proefsta.* 144–148.

Wisconsin College of Agriculture (1964): Chemical weed control recommendations for vegetable crop. *Circ. Univ. Wisconsin Ext. Serv.* 55.

WOODFORD, E. K., and S. A. Evans (1963): The weed control Handbook. Blackwells Scientific Publications.

WOOD, SUTHERLAND and STEPHENS (1960): Trials of chemical weedkillers in potatoes. *Proc. 5th Br. Weed Control Conf.* 5.

ZWEEP, W. VAN DER (1963): Personal communication.