RESIDUE REVIEWS

Residues of Pesticides and Other
Contaminants in the Total Environment

VOLUME 77

Editor
FRANCIS A. GUNTHER

JANE DAVIES GUNTHER

ADVISORY BOARD

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Riverside, California

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Foreword

Worldwide concern in scientific, industrial, and governmental communities over traces of toxic chemicals in foodstuffs and in both abiotic and biotic environments has justified the present triumvirate of specialized publications in this field: comprehensive reviews, rapidly published progress reports, and archival documentations. These three publications are integrated and scheduled to provide in international communication the coherency essential for nonduplicative and current progress in a field as dynamic and complex as environmental contamination and toxicology. Until now there has been no journal or other publication series reserved exclusively for the diversified literature on "toxic" chemicals in our foods, our feeds, our geographical surroundings, our domestic animals, our wildlife, and ourselves. Around the world immense efforts and many talents have been mobilized to technical and other evaluations of natures, locales, magnitudes, fates, and toxicology of the persisting residues of these chemicals loosed upon the world. Among the sequelae of this broad new emphasis has been an inescapable need for an articulated set of authoritative publications where one could expect to find the latest important world literature produced by this emerging area of science together with documentation of pertinent ancillary legislation.

The research director and the legislative or administrative advisor do not have the time even to scan the large number of technical publications that might contain articles important to current responsibility; these individuals need the background provided by detailed reviews plus an assured awareness of newly developing information, all with minimum time for literature searching. Similarly, the scientist assigned or attracted to a new problem has the requirements of gleaning all literature pertinent to his task, publishing quickly new developments or important new experimental details to inform others of findings that might alter their own efforts, and eventually publishing all his supporting data and conclusions for archival purposes.

The end result of this concern over these chores and responsibilities and with uniform, encompassing, and timely publication outlets in the field of environmental contamination and toxicology is the Springer-Verlag (Heidelberg and New York) triumvirate:

Residue Reviews (vol. 1 in 1962) for basically detailed review articles concerned with any aspects of residues of pesticides and other chemical contaminants in the total environment, including toxicological considerations and consequences.

Bulletin of Environmental Contamination and Toxicology (vol. 1 in 1966) for rapid publication of short reports of significant advances and discoveries in the fields of air, soil, water, and food contamination and pollution as well as methodology and other disciplines concerned with the introduction, presence, and effects of toxicants in the total environment.

Archives of Environmental Contamination and Toxicology (vol. 1 in 1973) for important complete articles emphasizing and describing original experimental or theoretical research work pertaining to the scientific aspects of chemical contaminants in the environment.

Manuscripts for *Residue Reviews* and the *Archives* are in identical formats and are subject to review, by workers in the field, for adequacy and value; manuscripts for the *Bulletin* are not reviewed and are published by photo-offset to provide the latest results without delay. The individual editors of these three publications comprise the Joint Coordinating Board of Editors with referral within the Board of manuscripts submitted to one publication but deemed by major emphasis or length more suitable for one of the others.

Coordinating Board of Editors

Residue Reviews Volume 77
Francis A. Gunther, Editor

"Linuron and Monolinuron"
by H. Maier-Bode and K. Härtel

Errata: On page 142, the displayed chemistry should be deleted.

Preface

That residues of pesticide and other contaminants in the total environment are of concern to everyone everywhere is attested by the reception accorded previous volumes of "Residue Reviews" and by the gratifying enthusiasm, sincerity, and efforts shown by all the individuals from whom manuscripts have been solicited. Despite much propaganda to the contrary, there can never be any serious question that pest-control chemicals and food-additive chemicals are essential to adequate food production, manufacture, marketing, and storage, yet without continuing surveillance and intelligent control some of those that persist in our foodstuffs could at times conceivably endanger the public health. Ensuring safety-in-use of these many chemicals is a dynamic challenge, for established ones are continually being displaced by newly developed ones more acceptable to food technologists, pharmacologists, toxicologists, and changing pest-control requirements in progressive food-producing economies.

These matters are of genuine concern to increasing numbers of governmental agencies and legislative bodies around the world, for some of these chemicals have resulted in a few mishaps from improper use. Adequate safety-in-use evaluations of any of these chemicals persisting into our foodstuffs are not simple matters, and they incorporate the considered judgments of many individuals highly trained in a variety of complex biological, chemical, food technological, medical, pharmacological, and toxicological disciplines.

It is hoped that "Residue Reviews" will continue to serve as an integrating factor both in focusing attention upon those many residue matters requiring further attention and in collating for variously trained readers present knowledge in specific important areas of residue and related endeavors involved with other chemical contaminants in the total environment. The contents of this and previous volumes of "Residue Reviews" illustrate these objectives. Since manuscripts are published in the order in which they are received in final form, it may seem that some important aspects of residue analytical chemistry, biochemistry, human and animal medicine, legislation, pharmacology, physiology, regulation, and toxicology are being neglected; to the contrary, these apparent omissions are recognized, and some pertinent manuscripts are in preparation. However, the field is so large and the interests in it are so varied that the editors and the Advisory Board earnestly solicit suggestions of topics and authors to help make this international book-series even more useful and informative.

"Residue Reviews" attempts to provide concise, critical reviews of timely advances, philosophy, and significant areas of accomplished or needed endeavor in the total field of residues of these and other foreign chemicals in any segment of the environment. These reviews are either general or specific, but properly they may lie in the domains of analytical chemistry and its methodology, biochemistry, human and animal medicine, legislation, pharmacology, physiology, regulation, and toxicology; certain affairs in the realm of food technology concerned specifically with pesticide and other food-additive problems are also appropriate subject matter. The justification for the preparation of any review for this book-series is that it deals with some aspect of the many real problems arising from the presence of any "foreign" chemicals in our surroundings. Thus, manuscripts may encompass those matters, in any country, which are involved in allowing pesticide and other plant-protecting chemicals to be used safely in producing, storing, and shipping crops. Added plant or animal pest-control chemicals or their metabolites that may persist into meat and other edible animal products (milk and milk products, eggs, etc.) are also residues and are within this scope. The so-called food additives (substances deliberately added to foods for flavor, odor, appearance, etc., as well as those inadvertently added during manufacture, packaging, distribution, storage, etc.) are also considered suitable review material. In addition, contaminant chemicals added in any manner to air, water, soil or plant or animal life are within this purview and these objectives.

Manuscripts are normally contributed by invitation but suggested topics are welcome. Preliminary communication with the editors is necessary before volunteered reviews are submitted in manuscript form.

Department of Entomology
University of California
Riverside, California
January 26, 1981

F.A.G.
J.D.G.

Linuron and monolinuron[*]

By

H. MAIER-BODE[**] and K. HÄRTEL[***]

Contents

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I. Introduction

In 1960 and 1961, linuron and monolinuron were the first substituted 3-aryl-1-methoxy-1-methyl-ureas that were introduced as herbicides in agriculture. Because of their favorable physical, chemical, and toxicological properties, particularly on account of the selectivity of their phytotoxic effects, they have found world-wide application in many fields of plant production. Their persistence in soil, plants, and the environment is limited to such a degree that, indeed, the desired herbicidal effects are not affected, yet the formation of undesirable residues in food or feed, as well as any accumulation in animate and inanimate nature, are avoided.

The world-wide application of linuron and monolinuron gave rise to a host of publications difficult to be surveyed, dealing with their effect on weeds, crop plants, and all kinds of other plants, as well as the environment; their practical application and mode of action; their toxicology in animals and in man; the quantity and tolerability of their residues in food and feed-stuffs, as well as in water; further with their behavior in plant and animal metabolism; their distribution, persistence, and degradation in soil, water, plants, and animals; with the composition, toxicology, and ecology of their degradation products and metabolites; their analytics; and with many other questions.

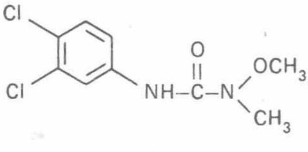
It seemed important to us to compile the contents of said publications, to review them critically, to classify them, and to present them as a monograph. Thus we wanted to contribute both to the present knowledge and to the future development of weed control with chemical means.[1]

Hoechst AG is thanked for valuable advice and support, especially for assistance in the procurement of difficultly available literature.

II. Chemical description of active agents

Linuron (I) is the common name of the herbicide 3-(3,4-dichlorophenyl)-1-methoxy-1-methyl-urea, $C_9H_{10}Cl_2N_2O_2$, mol. wt. 249.11.

Monolinuron (II) is the common name of the herbicide 3-(4-chlorophenyl)-1-methoxy-1-methyl-urea, $C_9H_{11}ClN_2O_2$, mol. wt. 214.66.



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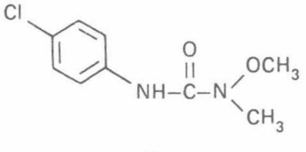

II

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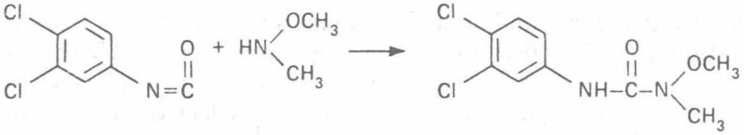
[1] Pesticides mentioned in the text are identified in Table CXXVII.

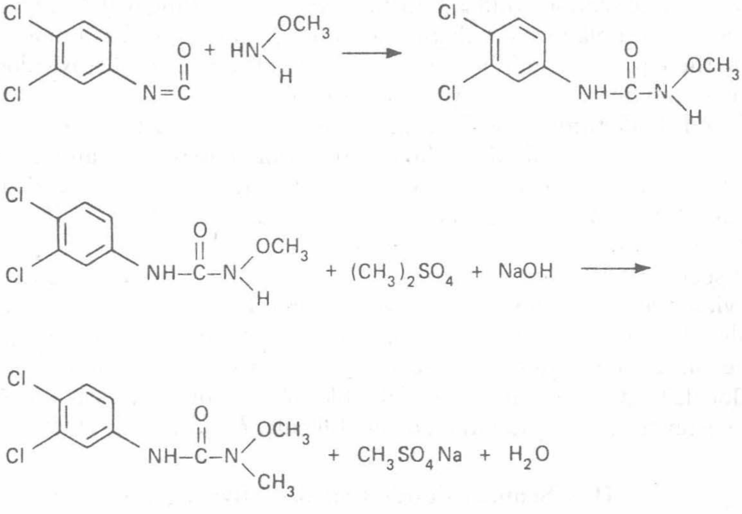
III. Synthesis of linuron and monolinuron

According to SCHERER *et al.* (1963), 3-aryl-1-methoxy-1-methylureas may be synthesized along the methods 1 to 4:

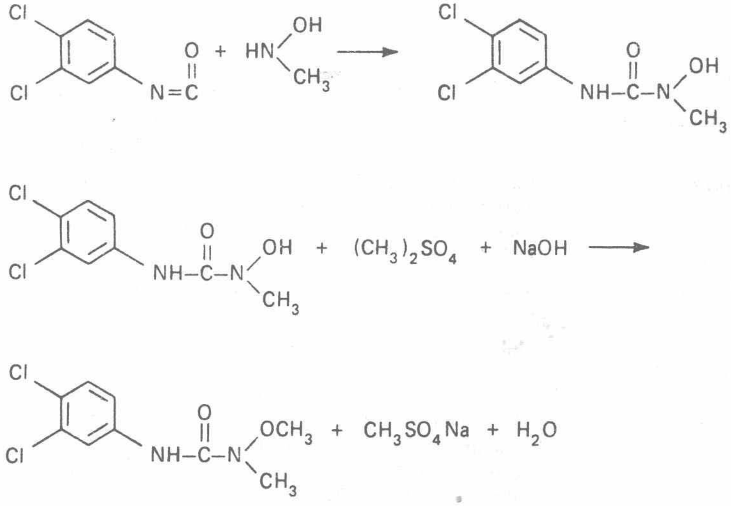
(1) Addition of *O,N*-dimethyl-hydroxylamine to arylisocyanates:



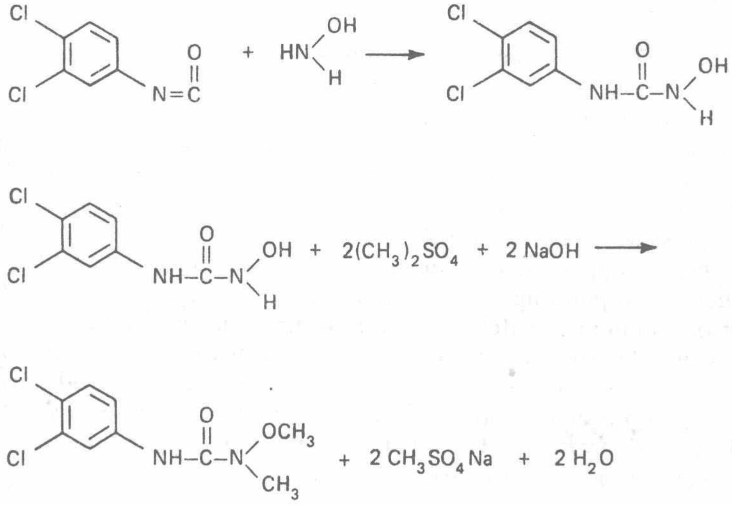
(2) Addition of *O*-methyl-hydroxylamine to arylisocyanates and methylation of the thus formed 3-aryl-1-methoxy-ureas with dimethylsulfate:



(3) Addition of *N*-methyl-hydroxylamine to arylisocyanates and methylation of the thus formed 3-aryl-1-methyl-ureas with dimethylsulfate:



(4) Addition of hydroxylamine to arylisocyanates and methylation of the thus formed 3-aryl-1-hydroxy-ureas with dimethylsulfate:



IV. Physical and chemical properties of linuron and monolinuron

Pure linuron and monolinuron are colorless and odorless crystalline substances. The active substances of technical grade occur as fine scales of beige-brownish to dark brown color with a faint amine-like odor. Their minimum purity is given as 90% (linuron) and 92% (monolinuron), respectively. Table I contains information on melting point, vapor pres-

Table I. *Physical properties of linuron and monolinuron.*

Property	Linuron	Monolinuron
Melting point[a] (°C)	pure: 93–94 tech.: 85–89	pure: 78 tech.: 75–78
Vapor pressure (Torr)	at 24°C, 1.5×10^{-5} at 60°C, 2.5×10^{-3} at 65°C, 6.2×10^{-3} at 75°C, 2.2×10^{-2}	at 22°C, 1.5×10^{-4} at 50°C, 4.5×10^{-3} at 60°C, 2.8×10^{-2}
Solubility in water at 25°C (mg/L) (ppm)	81	735
Solubility in organic solvents	soluble in acetone, ethanol, diethyl-ether, dioxane, methylenechloride, chloroform, benzene, xylene less soluble in aliphatic hydrocarbons (in petrolether of boiling limits 60–70°C approx. 2.5 g/L)	soluble in acetone, ethanol, dioxane, chloroform, benzene, toluene, xylene and other organic solvents

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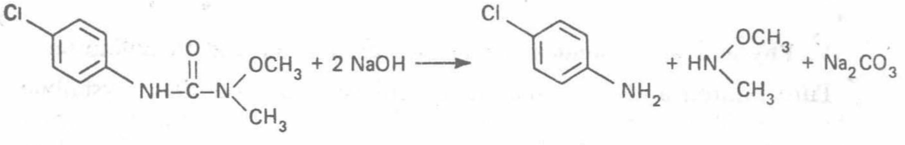
[a] The decomposition temperature of linuron in a sealed ampule is 275°C, in an open crucible 300°C (HOLLOMAN *et al.* 1976). As decomposition point, determined with the DuPont apparatus DTA 900, 210°C is given for linuron and 220°C for monolinuron (HOECHST AG 1965).

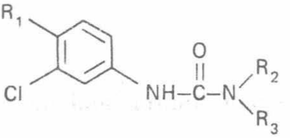
sure, and solubility of either herbicide (HOECHST AG 1965, MAIER-BODE 1971).

Linuron and monolinuron are stable on storing. Under normal storing conditions they are not oxidized by atmospheric oxygen. Under normal test conditions they are not subject to spontaneous combustion (up to 400°C) and are immune to impact. On account of their relatively high vapor pressures (Table I) they are volatile at elevated temperatures. This became apparent, e.g., in analytic investigations during drying of residues on evaporating from solutions of ^{14}C-labeled linuron in a drying closet on aluminum platelets. Within 48 hr radioactivity losses of up to 80% were determined (WALKER 1972 c). Towards water both of the herbicides are stable at room temperature during a prolonged period of time. By dilute acids and alkaline solutions they may be hydrolyzed, finally under formation of 3,4-dichloroaniline or 4-chloroaniline, respectively, e.g., according to the reaction scheme:



Purely chemical mechanisms such as oxidation, reduction, or hydrolysis play a minor role in soil, water, or plant as compared with the enzymatically directed reaction of biodegradation and photochemical reactions. From the degradation rates in aqueous suspensions of soil, linuron was determined to possess at temperatures around 100°C—calculated for 3 different types of soil—half-life periods of 13 to 71 years at 20°C under exclusion of biodegradation (Hance 1967 b and 1969 a).

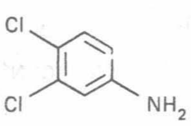
As far as is known (e.g., Knoevenagel and Himmelreich 1976), any organic compound under appropriate conditions is subject to photooxidative degradation reactions in the presence of air and water. Crosby and Li (1969) and Plimmer (1970) gave a good insight into the photochemistry of herbicides. From an aqueous linuron solution, after 2 mon, standing in sunlight (mid-May to mid-July, 1968), a mixture of substances was isolated containing: 69% unchanged linuron (I), 12% 3-(3-chloro-4-hydroxyphenyl)-1-methoxy-1-methyl-urea (II), 8% 3,4-dichlorophenyl-urea (III), and 2% 3-(3,4-dichlorophenyl)-1-methyl-urea (IV).



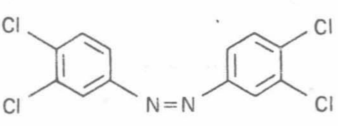
	R_1	R_2	R_3
I	Cl	OCH_3	CH_3
II	OH	OCH_3	CH_3
III	Cl	H	H
IV	Cl	H	CH_3

Hence some of the chlorine on the benzene ring of the linuron molecule had been replaced by hydroxyl (Rosen *et al.* 1969).

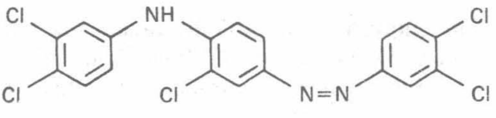
The further photolysis of the linuron degradation products is accelerated by sodium riboflavine-5′-phosphate (FMN) present in most living systems. The 3,4-dichloroaniline (V), detected among the photolysis products of linuron, is transformed under sunlight in the presence of FMN among others into 3,3′,4,4′-tetrachloroazobenzene (VI) and 4-(3,4-dichloroanilino)-3,3′,4′-trichloroazobenzene (VII) (Rosen and Winnett 1969, Rosen *et al.* 1970).



V



VI



VII

In experiments by GRYZLOVA (1976) 85 to 90% of the 3,4-dichloroaniline was degraded under field conditions in direct sunlight within 3 to 5 hr.

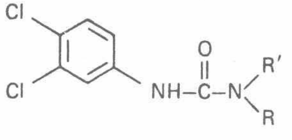
The rate of degradation is a function of the radiation dose. 3,4-dichloroaniline is also photolyzed under water, but the intensity of the process diminished with increasing thickness of the water layer. After UV irradiation of a solution of 3,4-dichloroaniline in a mixture of water and methanol (1:1), 4-chloroaniline, aniline, 3,3′,4,4′-tetrachloroazoxybenzene, a dechlorination product of the latter, and hydrazobenzene were ascertained as transformation products. Irradiation of undissolved 3,4-dichloroaniline produced 4-chloroaniline and 3 further metabolites; on irradiation in the gas phase small amounts of 4-chloroaniline and aniline were found as reaction products (MANSOUR *et al.* 1975).

Monolinuron was extensively degraded under UV irradiation (wavelength > 300 nm, 23 hr) in water or methanol or even in the solid phase. Among the degradation products in liquid medium, 4-chloroaniline was found (KOTZIAS *et al.* 1974).

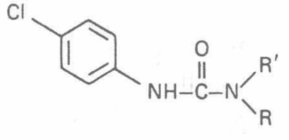
V. The herbicide effect and application of linuron and monolinuron

a) The herbicide effect of linuron and monolinuron

Linuron (I) and monolinuron (III) are, as with other phenyl urea compounds, translocation herbicides. They are closely related to diuron (II) and monuron (IV) and differ from them by the fact that one methyl group is replaced by a methoxy group. Despite this close relationship they significantly differ in their biological and physicochemical behavior from the two dimethylurea compounds (ANONYMOUS 1962, RADEMACHER 1962, HAERTEL 1962, STRYCKERS and BRAECKMAN 1962, KURATLE 1968, MAJUMDAR 1968, MAIER-BODE 1971, PALM 1971).



I : R = CH_3 R′ = OCH_3
II : R = CH_3 R′ = CH_3



III : R = CH_3 R′ = OCH_3
IV : R = CH_3 R′ = CH_3

Whereas diuron and monuron are chiefly taken up by the roots (MUZIK *et al.* 1954, HARGAN 1964, KURATLE 1968, PERRY 1973) and are known as sparingly selective, rather persistent herbicides (HILL *et al.* 1955, HAERTEL 1962, MAIER-BODE 1971), linuron and monolinuron are taken up almost equally well via the root, shoot, and leaf (HAERTEL 1962, KURATLE 1968, MAIER-BODE 1971, WALKER 1973 a). They possess a good tolerance towards a series of crop plants (carrots, parsnips, and other umbelliferous plants, cereals, field corn, potatoes, phaseolus beans, soybeans, tobacco) under retention of their good weed action. Due to their relatively short residual effect in the soil which, however, is sufficiently long for agricultural practice, there are no problems of crop rotation even in sensitive crops (cp. also section VII *a*). Thus 1.0 to 2.0 kg linuron and monolinuron are degraded already within 2 to 4 mon in the soil (HILL *et al.* 1962, HOMBURG and SMIT 1964, KURATLE 1968, MAJUMDAR 1968, BURNSIDE *et al.* 1969, MAIER-BODE 1971), whereas, according to HILL *et al.* (1955), 1.1 to 2.2 kg diuron and monuron, respectively, disappear as late as 4 to 8 mon from the soil. Soil texture differences (sandy loam, very fine sandy loam, silt loam, and silty clay loam) had a greater influence on herbicide residue carryover than did climatic differences (BURNSIDE *et al.* 1969).

The herbicide action of linuron and monolinuron—as with other phenyl ureas—is primarily based on the inhibition of photosynthesis (KURATLE 1968, MAIER-BODE 1971, PALM 1971), the return of emitted electrons to the chlorophyll in the oxidation of water in the noncyclic phosphorylation being inhibited (OVERBECK 1962). But they also cause disturbances of sugar synthesis (KURATLE 1968, UPCHURCH *et al.* 1969, PARAMONOVA 1971, LESZCZYNSKI *et al.* 1972) and of protein metabolism (FREED 1953, LALOVA 1971 and 1973, PARAMONOVA 1971, LADONIN *et al.* 1973 a, REJOWSKI *et al.* 1973, GRZESIUK *et al.* 1973 a and c, KOZACZENKO 1974), they interfere in enzymatic processes in plants (GRZESIUK *et al.* 1973 a, b, and c, DECLEIRE *et al.* 1974 a and b), and cause disorders of cytogenesis, especially cell division and mitosis (KURATLE 1968, GRANT 1962/63 and 1964/65, WUU and GRANT 1966, DEYSSON *et al.* 1974). Furthermore, they have an influence on transpiration, respiration, and uptake of anions and cations via the root (SMITH and BUCHHOLTZ 1964, OORSCHOT 1964 and 1970, OLECH 1967, HOGUE 1967, KURATLE 1968, NASHED and ILNICKI 1966, 1967 a, 1968, and 1969, PARAMONOVA 1971).

According to MAJUMDAR (1968) the differences in herbicide activity are negligible between linuron and monolinuron under comparable conditions. They both have approximately the same spectrum of activity against annual weeds (Table II) and differ little even in their degree of selectivity against crop plants, yet, indeed, to such a degree that they present different focuses of application and overlapping fields of application (STRYCKERS and BRAECKMAN 1962, HAERTEL 1962). Thus under European climatic conditions, monolinuron is preferably recommended in dwarf-beans and potatoes for preemergence application, yet not in carrots and other umbelliferous plants. In carrots and other umbelliferous plants and field corn, the focus for linuron application is in pre- and postemergence operation.

Climate, type of soil and its humus content, temperature and soil mois-

Table II. *Effects of various linuron and monolinuron doses on germinating weed seeds and seedlings (% dead seedlings)* (after MAJUMDAR 1968).

Days after application	*Alopecurus myosuroides*[a]				*Chenopodium album*[a]				*Stellaria media*[a]				*Sinapis arvensis*[a]				*Matricaria inodora*[a]			
	U	N/2	N	2N	U	N/2	N	2N	U	N/2	N	2N	U	N/2	N	2N	U	N/2	N	2N
									Germinating seeds											
Linuron																				
7	0	4	17	25	4	37	37	12	0	28	65	90	0	80	100	100	0	44	70	77
10	4	10	19	30	5	56	75	80	0	90	100	100	0	100			0	90	95	100
13	4	20	25	45	9	100	100	100	0	100										
16	4	29	39	65																
21	6	66	95	100																
Monolinuron																				
7	0	0	0	14	0	4	0	27	0	0	12	100	0	10	44	95	0	0	22	70
10	0	0	2	40	0	10	7	64	0	24	92		0	39	75	100	0	17	75	97
13	0	4	9	67	7	57	42	92	0	59	100		0	65	85		0	55	95	100
16	0	9	20	80	10	87	87	100	0	100			7	79	100		0	87	100	
21	0	24	77	100																
									Seedlings											
Linuron																				
7	0	0	2	0	4	25	62	97	14	35	95	97	5	90	97	100	9	64	100	100
10	2	0	10	57	4	39	85	100	22	70	100	100	5	100	100		19	100		
13	2	10	30	89	15	59	100		22	99										
16	2	29	30	97																
Monolinuron																				
7	0	0	0	14	0	0	4	5	0	12	22	57	0	25	77	94	0	0	45	19
10	0	0	7	50	0	0	29	67	0	37	64	84	2	100	100	100	7	24	77	80
13	0	2	10	75	12	20	69	100	0	72	92	90					14	39	86	94
16	2	0	20	100																

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[a] U = untreated, N = normal dose.