Technological Advances and Constraints in Weed Control

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Technology

Humans are supposed to be artistic and able to think or reason.

Early creativity produced the basic means to survive in harsh environments.

“Happiness, for the bee as for the dolphin, is to exist.

For man, it is to know existence and to marvel in it.”

– Jacques-Yves Cousteau (1910 – 1997)

Creativity + Thinking = Knowledge

Knowledge about life processes and links between them

Understanding of nature

Ability to control other life forms

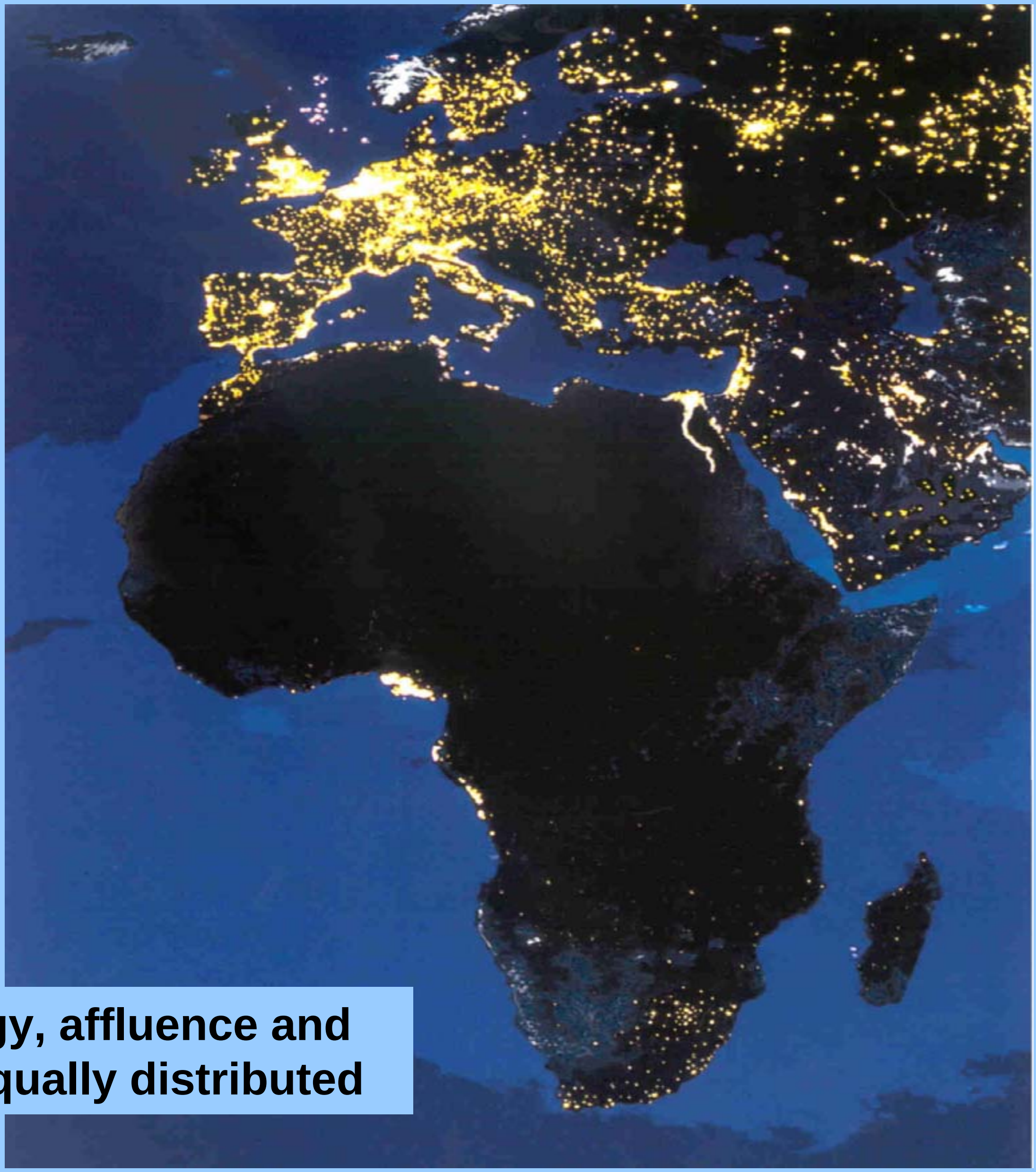
Domestication of plants and animals

Agriculture

Increased chances of survival

Civilization

Science & Technology



Technology, affluence and food not equally distributed

Irreversible, progressively complex technological processes formed *Homo sapiens*.

Five million people 30,000 years ago have burgeoned to six billion.

Half live in poverty, and the total world population is expected to increase by half — perhaps even to double — by 2050.

Falling back on earlier (“traditional”) technology is clearly a step backward.

Objective criticism of modern technology must consider alternative technologies that would, at least, sustain life at the present level.

Innovation ⟲ Technology

Thanks to technological tools, new environments hold few challenges for us.

Global Positioning System (GPS)

“All technological and scientific inquiries are simply different ways of accessing and understanding the world around us”.

“The only true voyage of discovery is not to go to new places, but to have other eyes.**”**

– Marcel Proust

Science and technology are inextricably linked.

Both have been regarded with tragic scepticism for as long as critical inquiry has existed.

Without technology "our intellectual grasp could not have exceeded our biological reach."

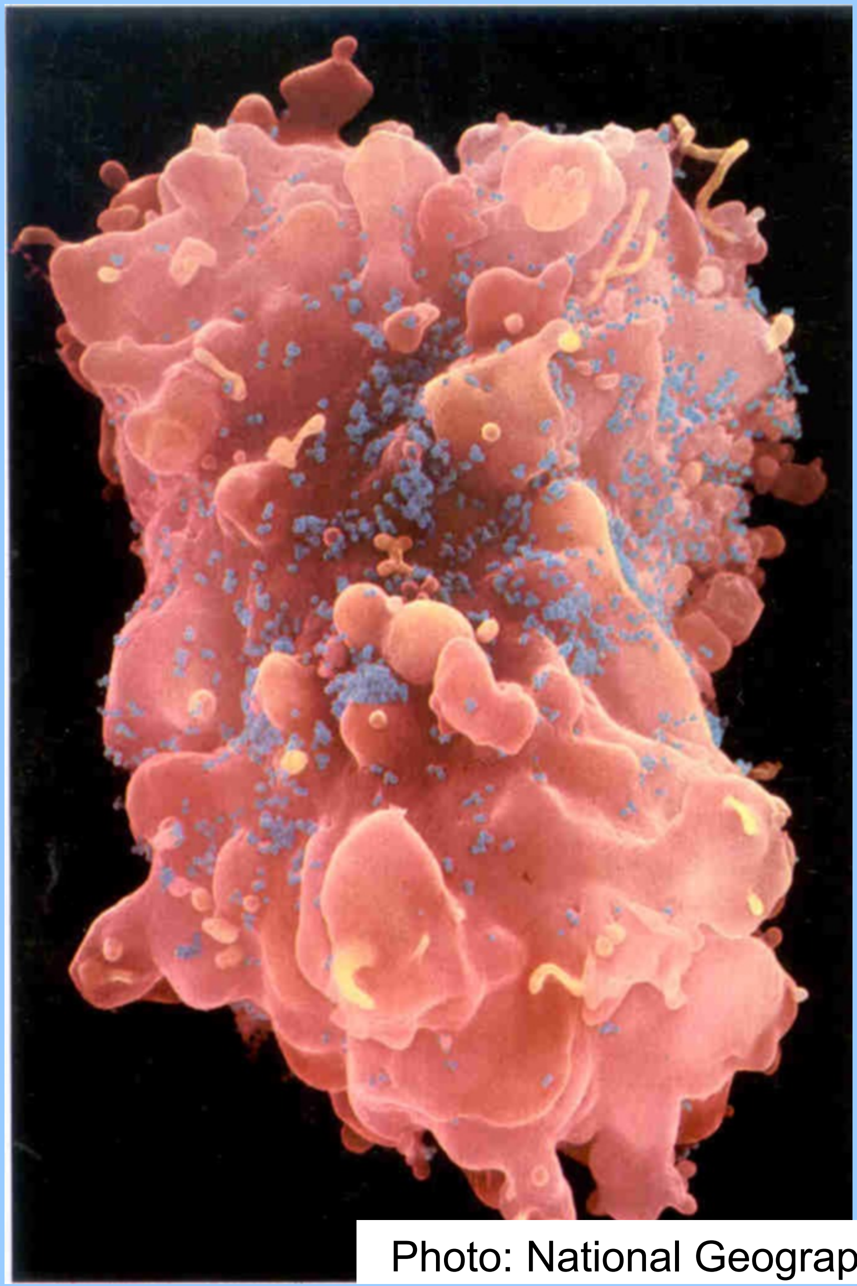


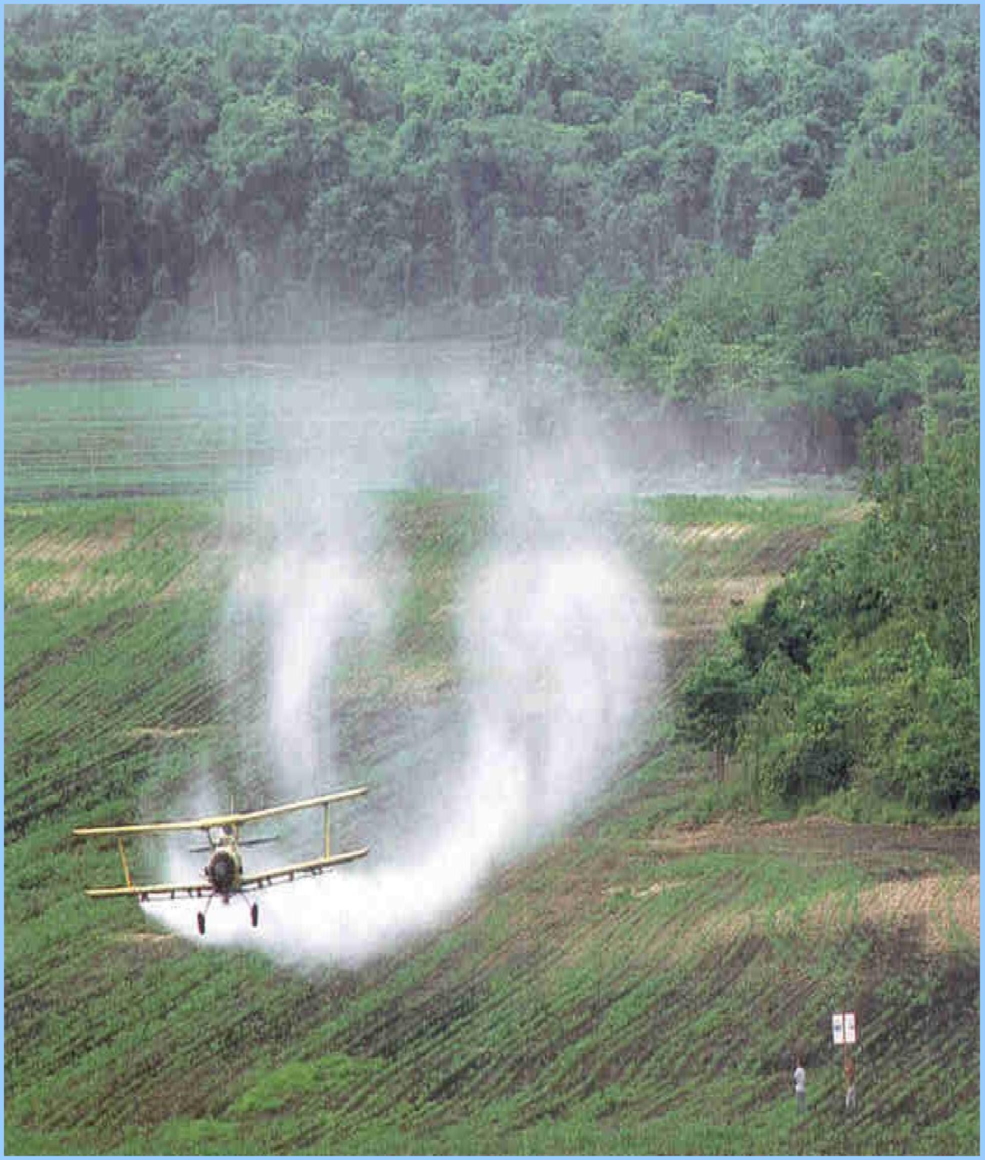
Photo: National Geographic

AGRICULTURE

Humans encroach on nature, and nature disregards the boundaries we set.

Agriculture indisputably causes disturbance of the environment.

What can be disputed are claims that agriculture's role in feeding the world's populations is outstripped by negative impacts on the environment.



More people means less land is available for food production.

Human population increases demand higher crop production.

Increased crop yields demand higher pesticide usage.

Plants are the main source of food on earth

Ever since humans domesticated plants they would have had problems with weeds.

The term “weed” is used for plants that interfere with human activities and aspirations.

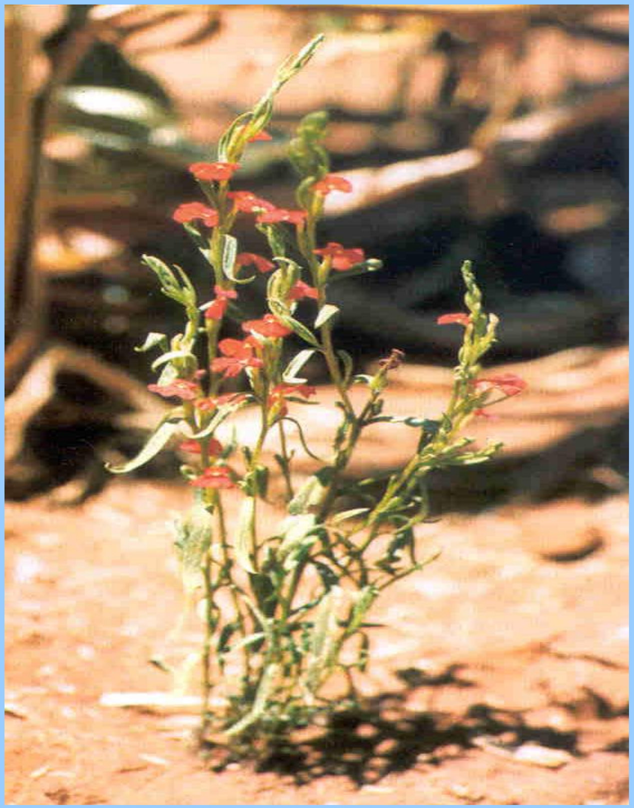
Mother Nature knows no weeds, nature has no vacuums, and do not respect human boundaries.


Photo: Syngenta

Arabidopsis thaliana

A. thaliana **is a model organism for genetic studies on plants. Its genome is one of the smallest in the plant kingdom (45x smaller than maize). Sequencing of the whole genome was completed in 2000.**

Striga asiatica



S. asiatica **is one of the world's worst weeds. It parasitises grass crops such as maize and sorghum.**

Mechanisms of weed interference with desirable plant species

Unlike diseases and pests, weeds do not attack other plants, but rather interfere with growth and development through the phenomena of *competition* and *allelopathy*.

Weed competition and allelopathy may adversely affect crop vigour and reduce the size and quality of the harvest.

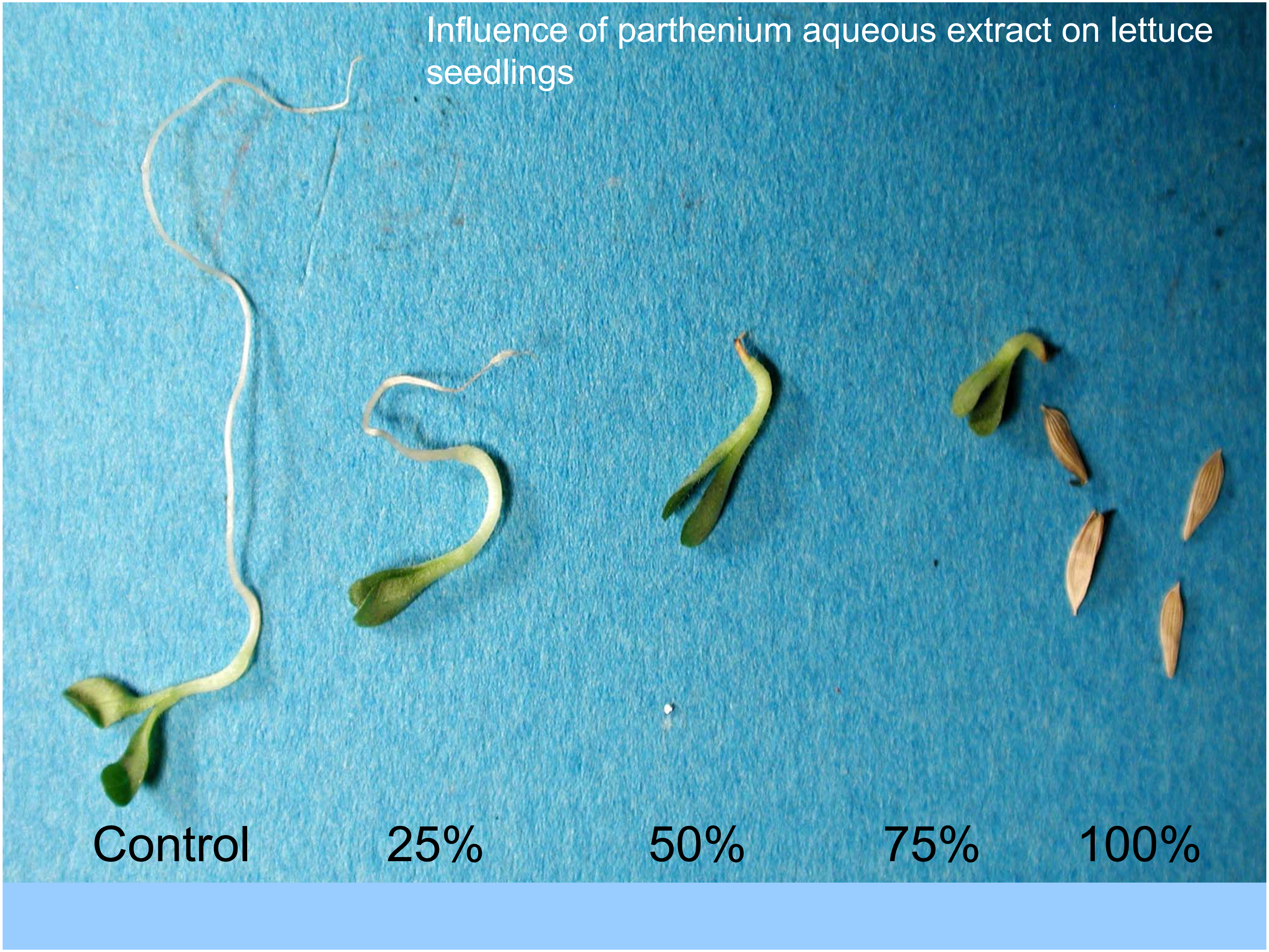
Competition occurs for growth factors (water, light, nutrients).

Allelopathy involves the production and release by plants of phytotoxins (allelochemicals) which may affect individuals of the same or other species.

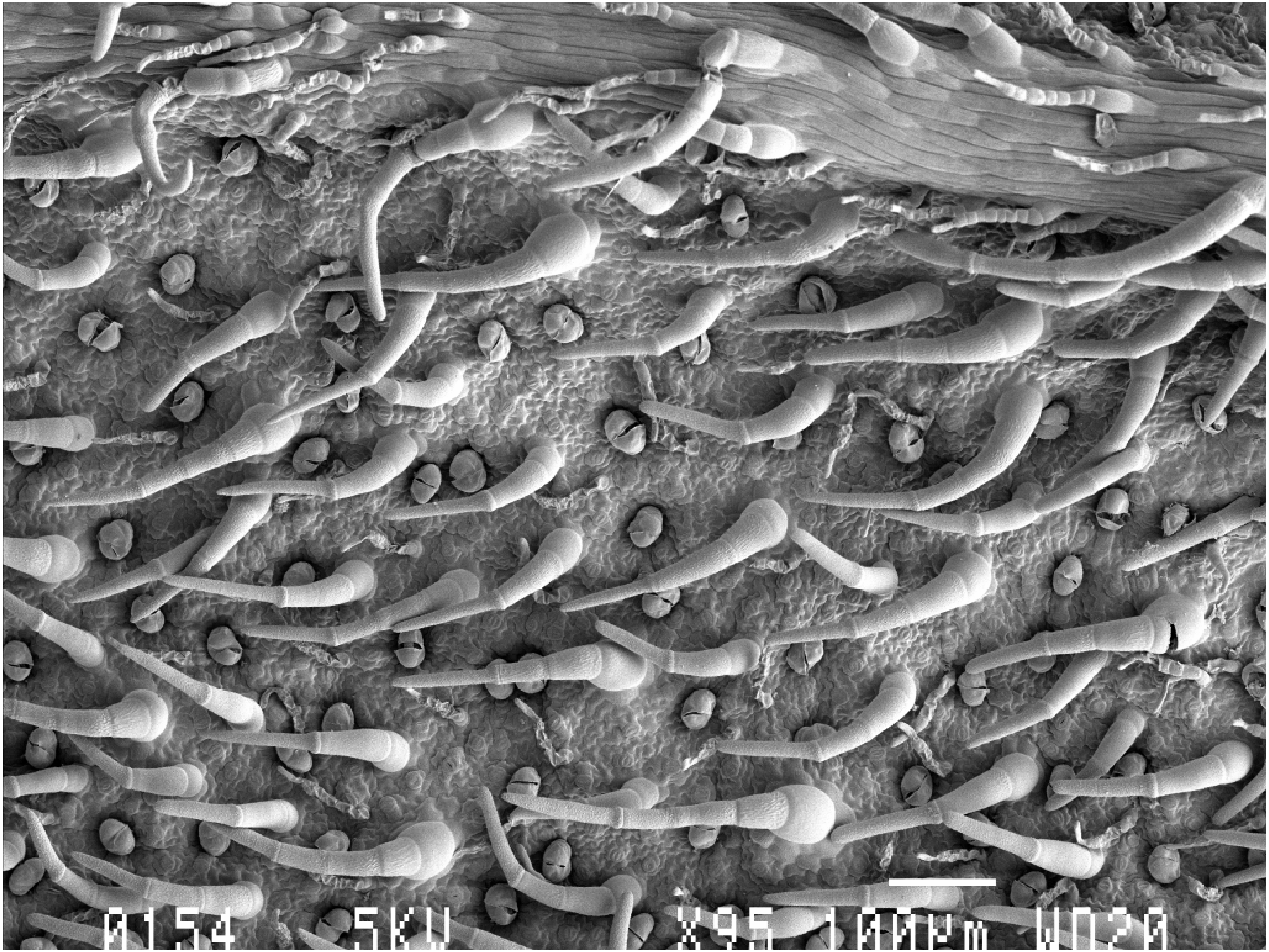
Competition occurs only when growth factors (water, light, nutrients) are in limited supply and the need of interacting species exceed the supply.

Parthenium hysterophorus
"Parthenium"
"Demoina weed"

- Asteraceae
- annual (?) herb
- deep taproot
- erect stem, woody with age
- multiple branches
- height up to 2 m
- white flowers; five seeds


Influence of parthenium aqueous extract on lettuce seedlings
Control
25%
50%
75%
100%

Root system of lettuce (cv.Great Lakes) *grown in presence of P. hysterophorus*


0154 5KV X95 100µm WD20


0153 5KV X1,800 10µm WD20

Problems associated with weeds

Weeds cause harm in both agricultural and natural ecosystems.

Direct losses: Crop yield and quality

About 12% of crop yield loss in the USA, and up to 25% in developing countries, attributed to weeds.

Annual financial loss = $33 billion (12% yield loss)

+ $6 billion (weed control)

Indirect losses: Reduced land value

Water loss

Toxicity and allergies

Reduction in biodiversity

Yield reductions in the absence of crop protection

(In brackets: reductions despite crop protection measures)

	Reductions due to:		
	Weeds	**Pests**	**Diseases**
Wheat	**24 (12)**	**11 (9)**	**17 (12)**
Maize	**29 (13)**	**19 (15)**	**12 (11)**
Soybeans	**35 (12)**	**13 (10)**	**11 (9)**
Cotton	**36 (13)**	**37 (15)**	**10 (11)**

- adapted from Oerke et al. 1994

South Africa is stressed i.t.o. available water

Woody alien plants use 3.3 billion m^3 water p.a.

Forestry plantations use 1.4 billion m^3 water

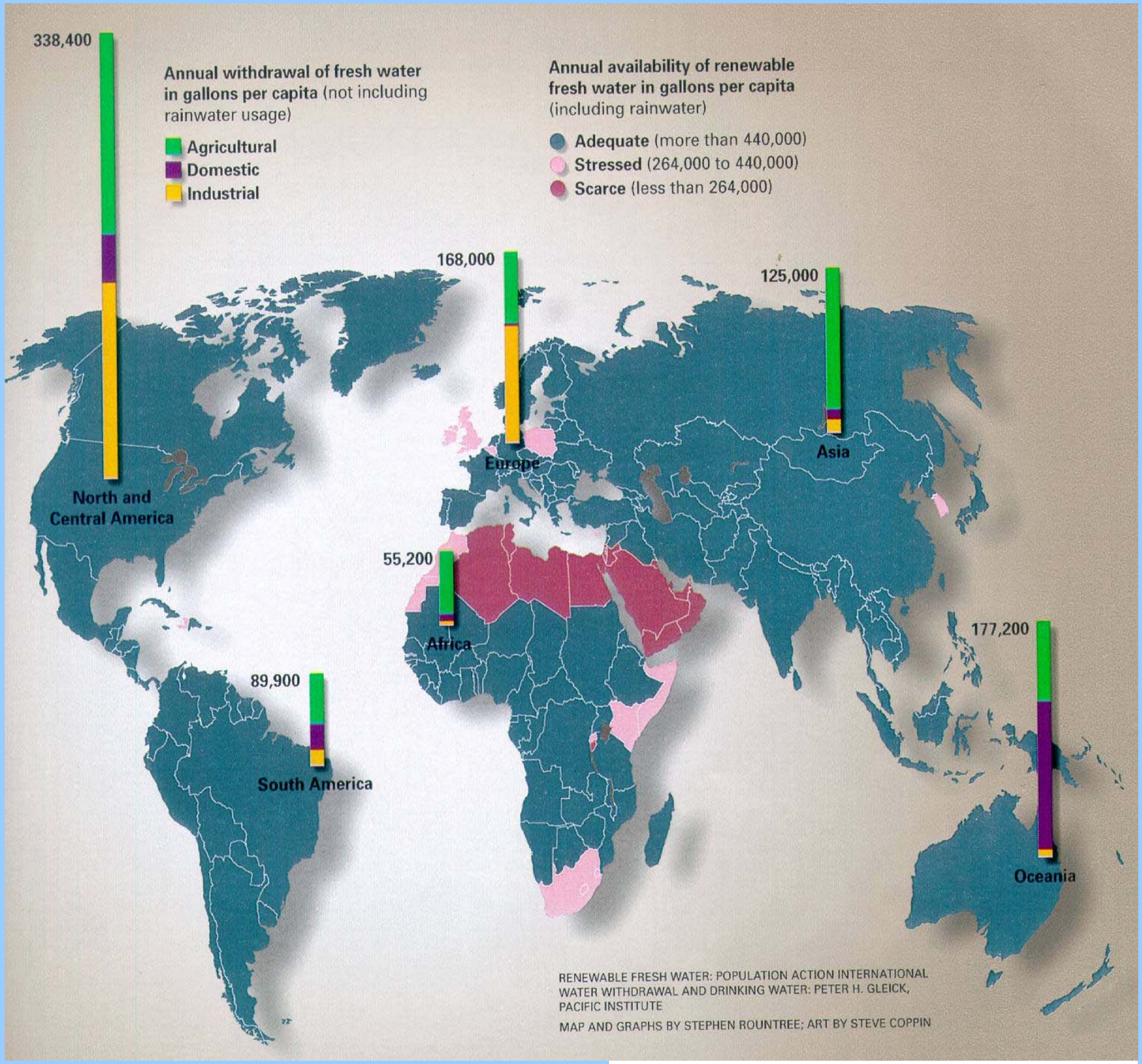


Photo: National Geographic

What's wrong with this picture?

National Geographic

Weeds have to be controlled because they do harm and cause problems.

1. “Control at any price” strategy

- Total control the objective.
- Prohibitive cost (time/labour/money/environment).

2. “Economic threshold” strategy

Q: What level of weed presence can be tolerated?

- Control only when needed.
- Cost of control should be less than profits gained as a result of control.
- Less pressure on environment.

3. “Ecological-economic threshold” strategy

Q: What level of weed presence is needed?

- Environmental concerns are overriding.
- Intensified control practices have reduced biodiversity on arable land.
- Past 50 years has seen loss of 20 to 40% of agricultural weed species in Europe.
- Is biodiversity on farmland important for sustainable crop production?

Weed control practices

Mechanical (hand-hoeing, machinery)

Cultural (crop/cultivar selection, crop rotation, mulching, etc.)

Biological (natural enemies)

Chemical (herbicides)

Mechanical control: tillage of soil

S. O. Duke, 2002

Mechanical control: flaming with gas

National Geographic

Wishful thinking!

National Geographic

<u>Advances in biocontrol</u>

Increasing numbers of biocontrol agents are being released on more alien invasive species.

“Mycoherbicides” are fungal suspensions that are applied in much the same way as conventional herbicides.

International co-operation for obtaining biocontrol agents is at a high level.

Low environmental impact carries public approval.

Opuntia stricta in Kruger Nat. Park

Fruit eaten by baboons and elephant

Cochineal on cladodes

After

Constraints for biocontrol

Application in cropping systems limited by:

- instability of the biocontrol agent’s environment
- use of pesticides;
- effects develop too slowly.

Herbicides

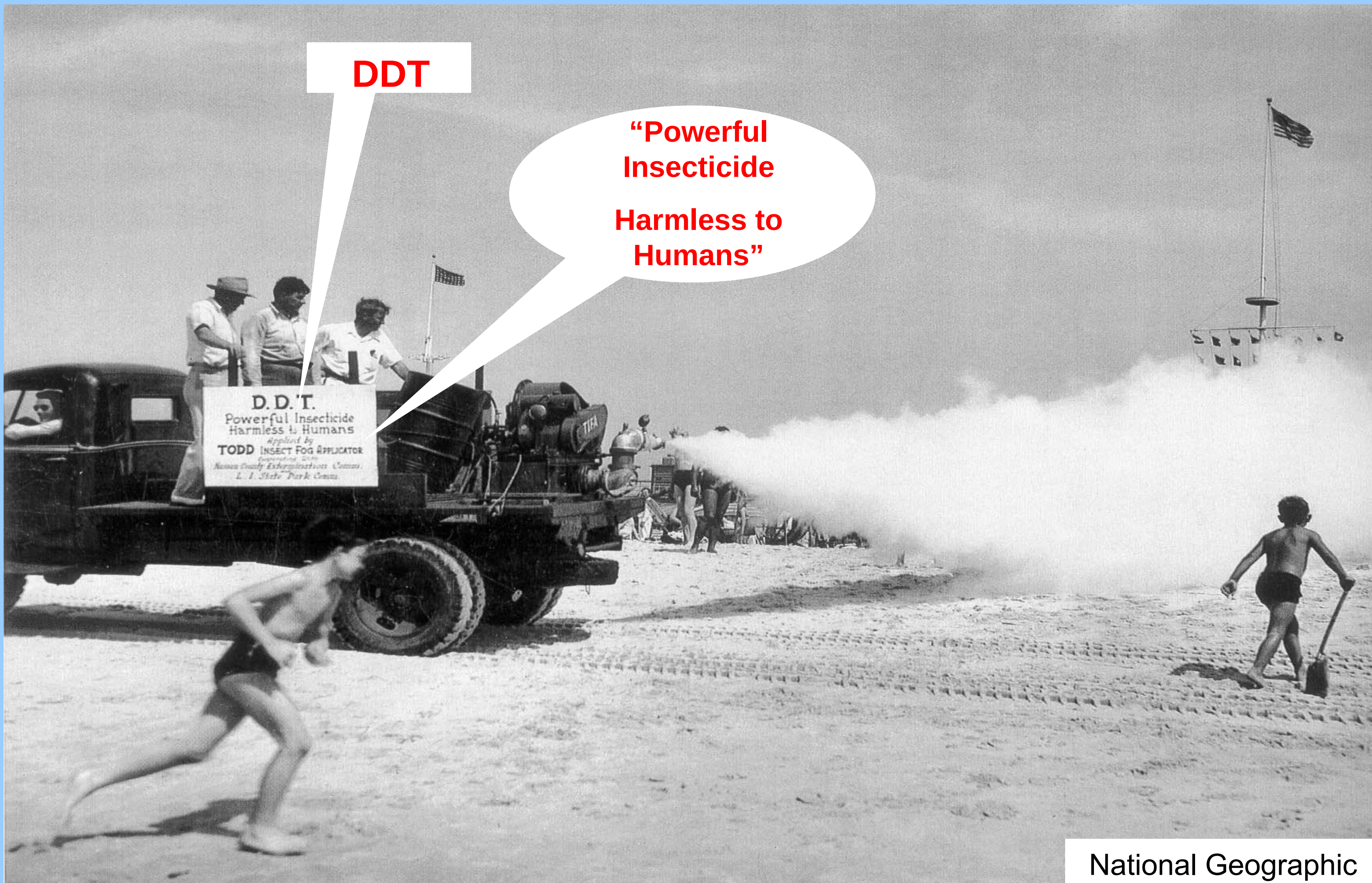
Herbicides represent the “technological crutch” on which weed control relies the most.

Herbicides account for ±70% of pesticides (by volume) used in both the USA and RSA.

They differ from other pesticides because selectivity towards the plant (crop) needing protection is a prime consideration.

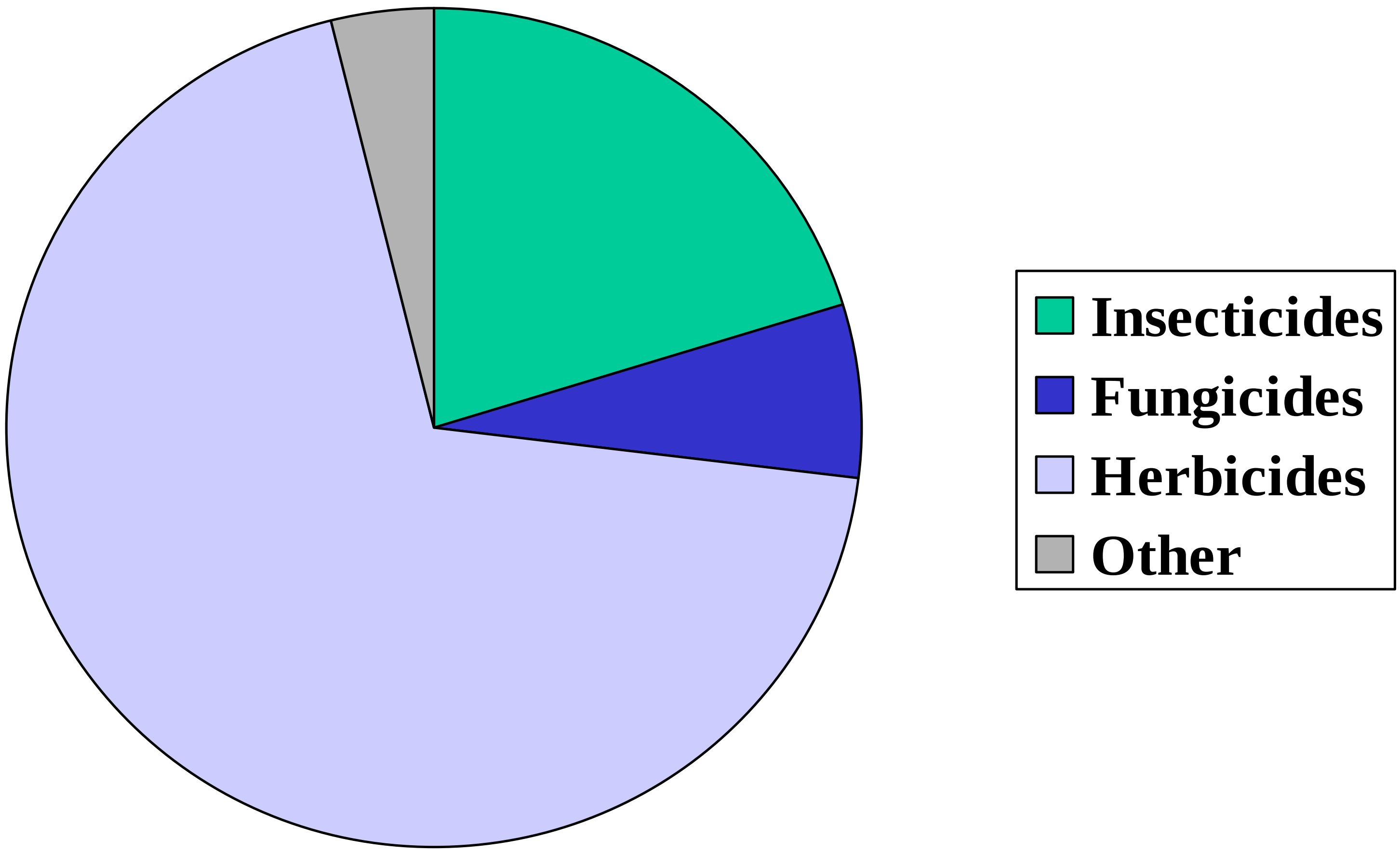
Because plant and animal life processes differ substantially, herbicides are generally “safer” than other pesticides.

CIRCA 1972: sand flea control on USA beach



National Geographic

Crop protection pesticide sales



S. O. Duke, 2002

<u>Advances in chemical control (= herbicide use)</u>

- Application techniques
- Formulation
- New chemistry → increased biological activity
  → novel mechanisms of action
- Genetic modification to produce herbicide-resistant crops
- Herbicides from natural products

Application Technology

A. Site-specific application

GPS / GIS technology

B. Target (weed)-specific application

Infrared sensors

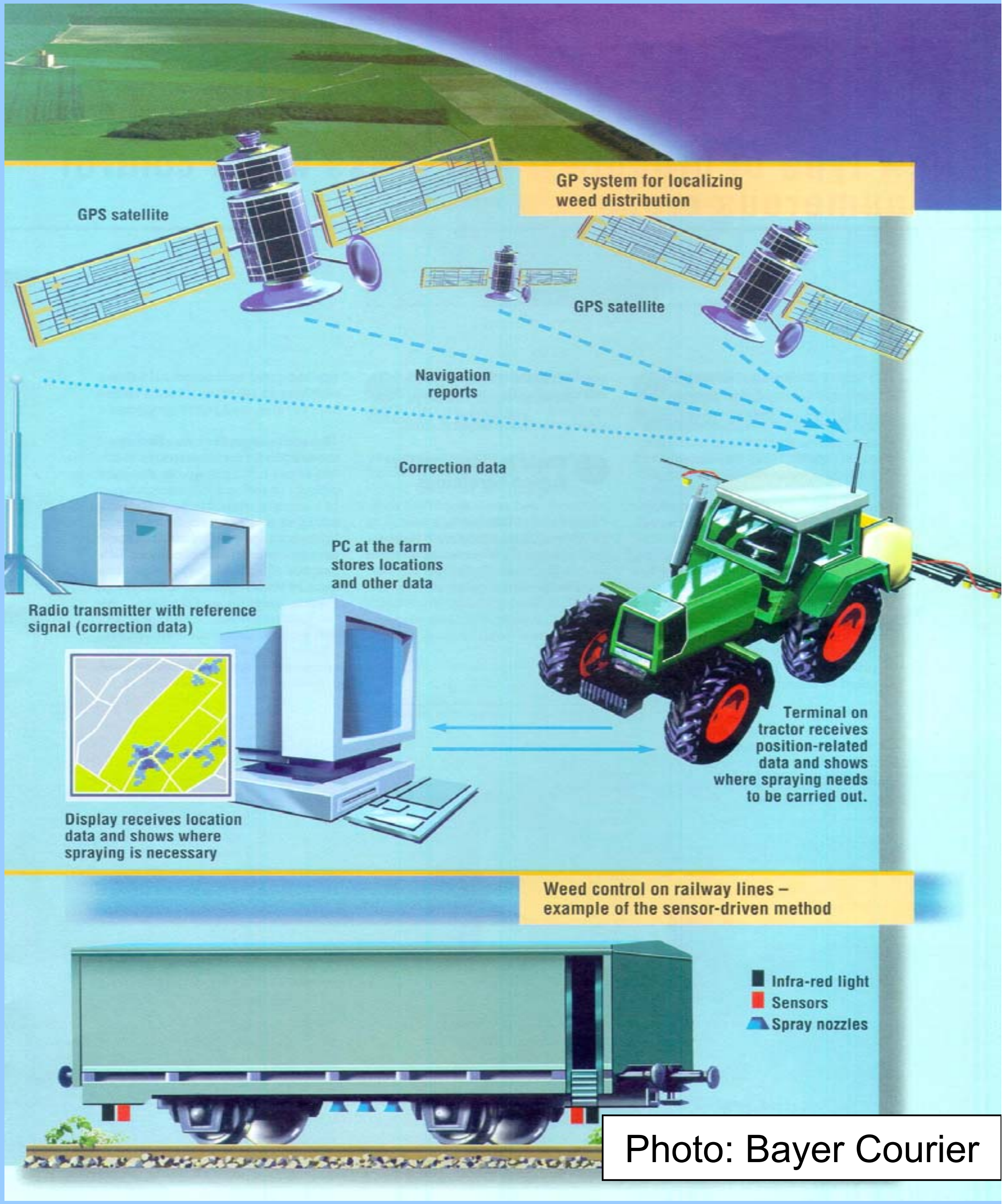
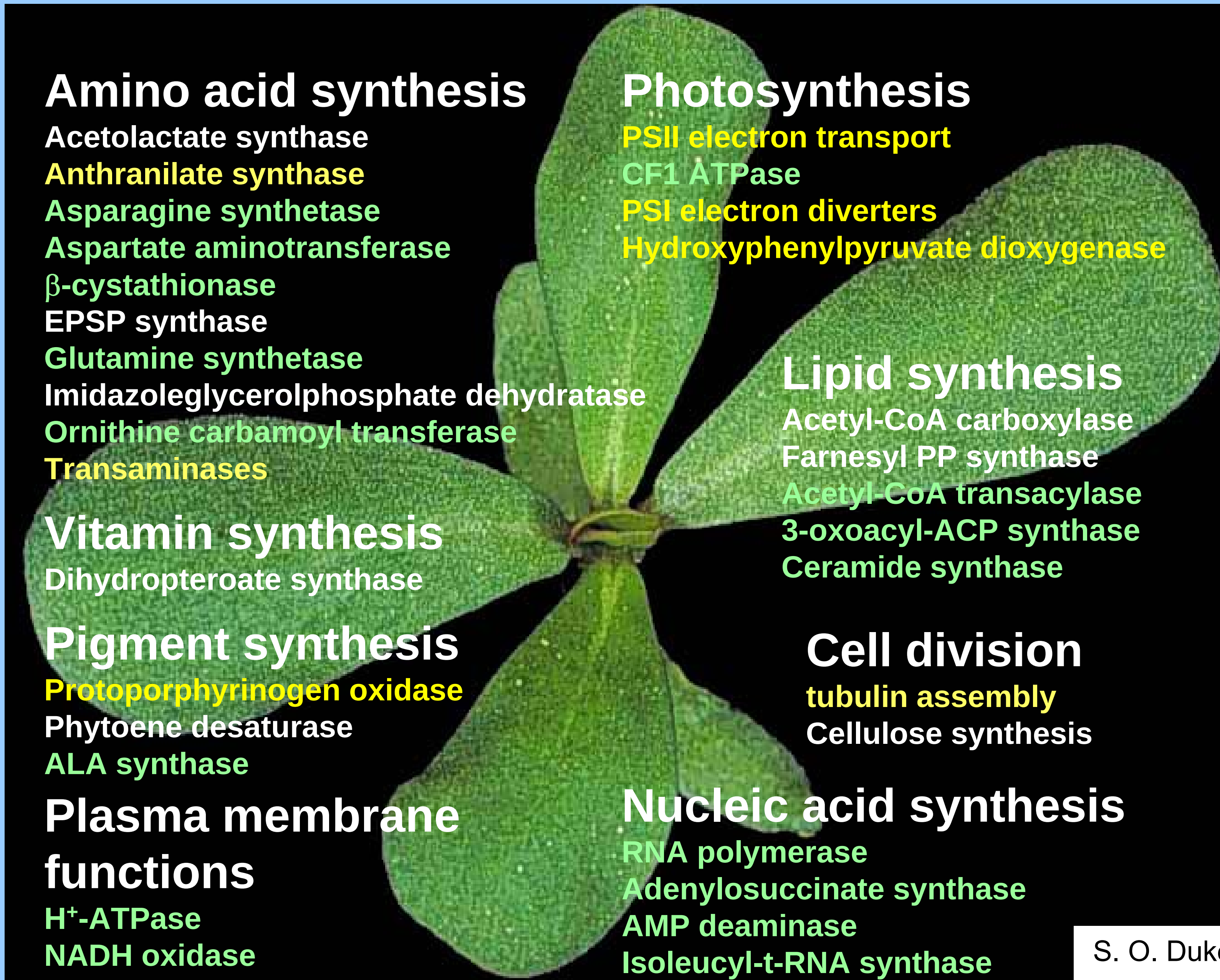


Photo: Bayer Courier

New molecular target sites



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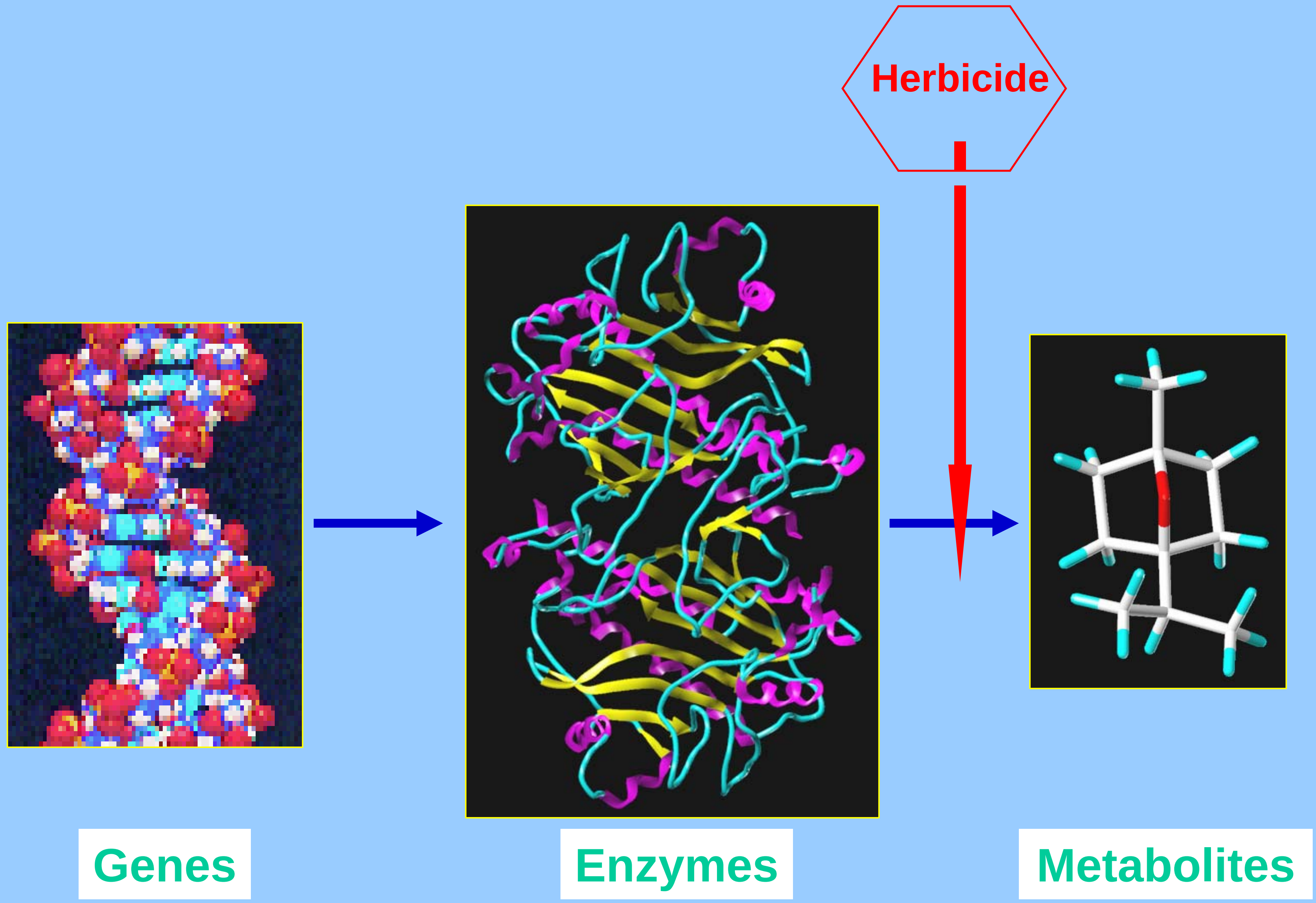


Adapted from Duke, 2002

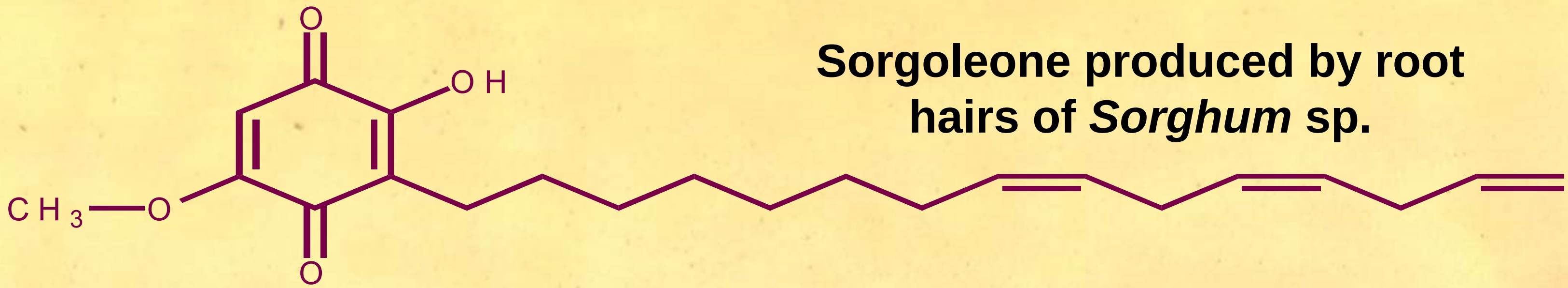
Development of novel herbicides

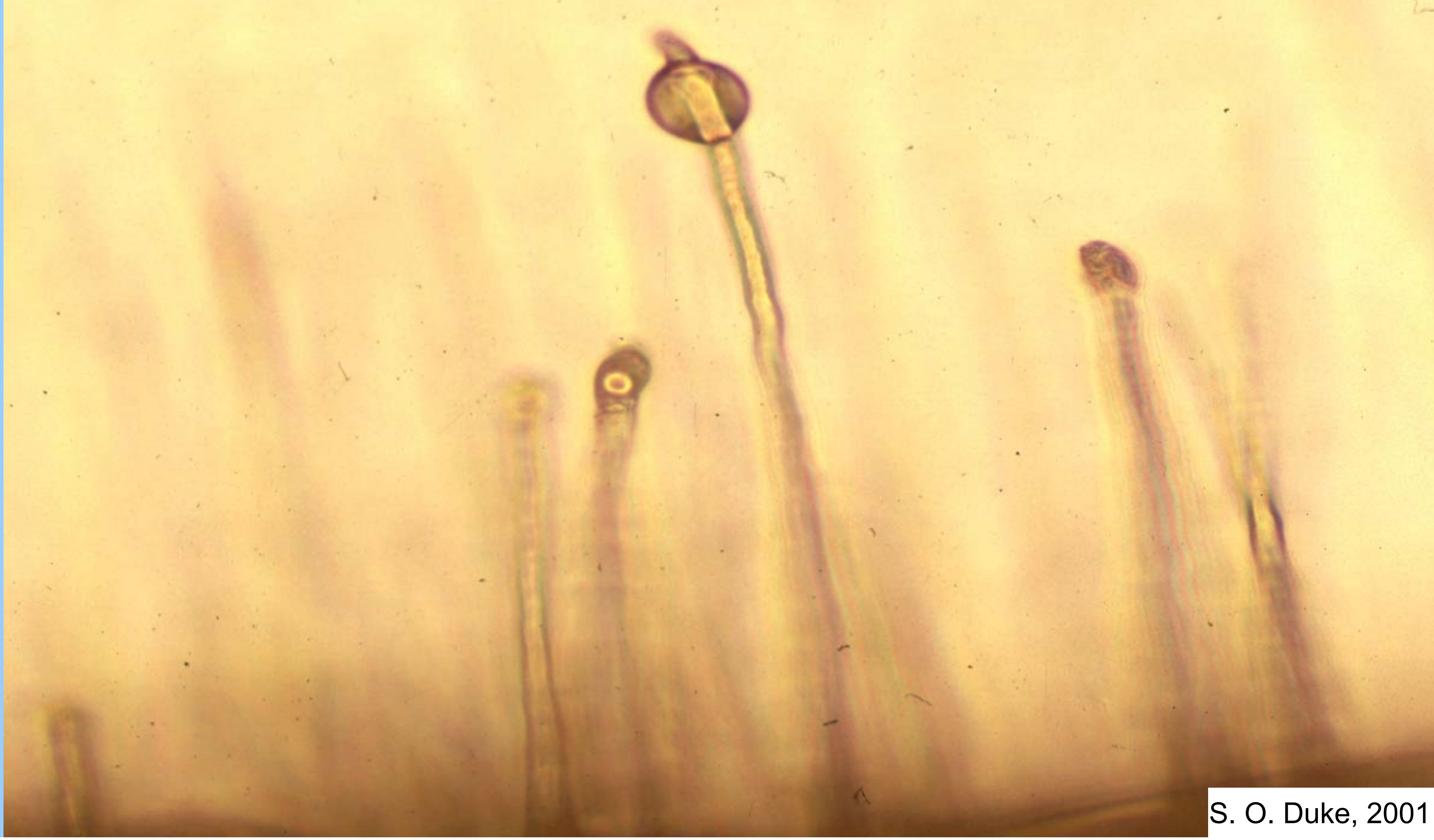
Callistemon citrinus

The allelochemical leptospermone was identified in *C. citrinus*.
Leptospermone inhibits the enzyme phenylpyruvate dioxygenase.
Leptospermone was used to design the herbicide analog mesotrione.

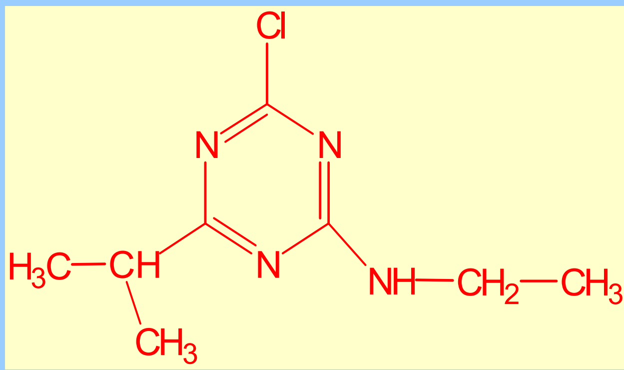
Photo: Syngenta

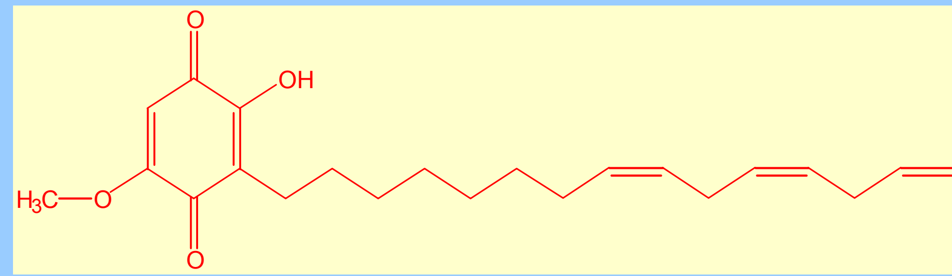
Sorgoleone produced by root hairs of *Sorghum* sp.





S. O. Duke, 2001

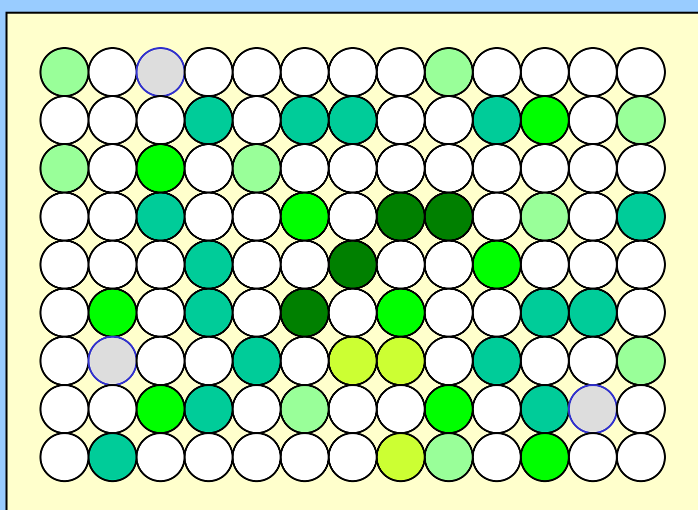




Atrazine

PSII inhibitor

Sorgoleone



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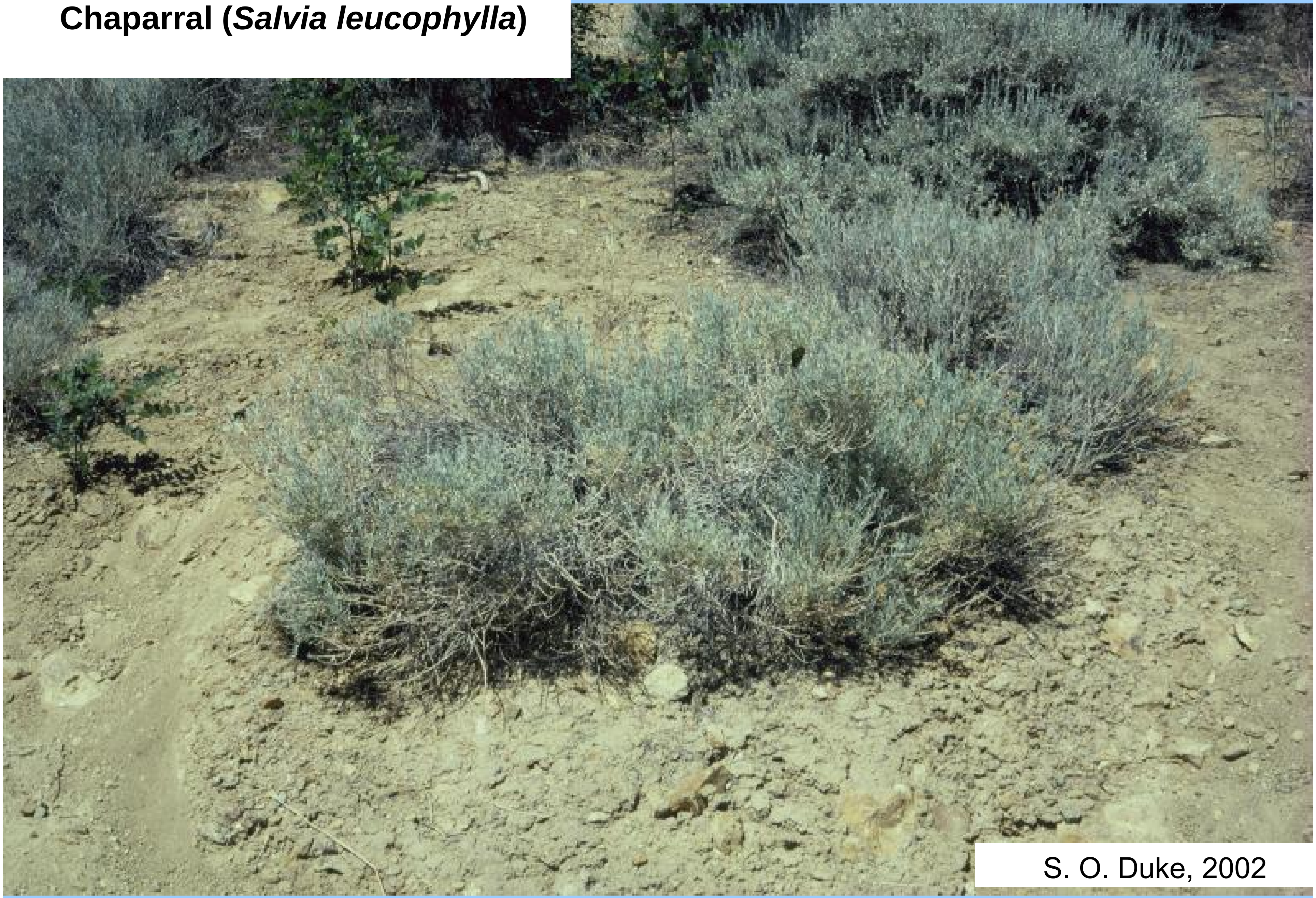
S. O. Duke, 2002

Chaparral (*Salvia leucophylla*)



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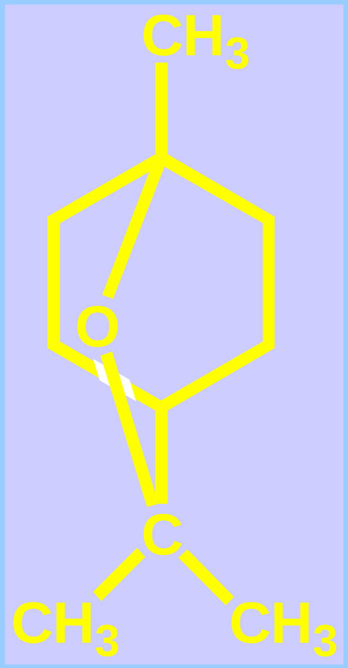
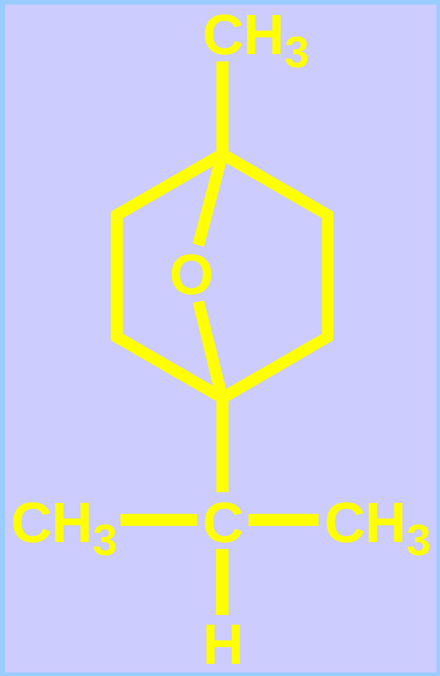
Natural Monoterpene Analogs



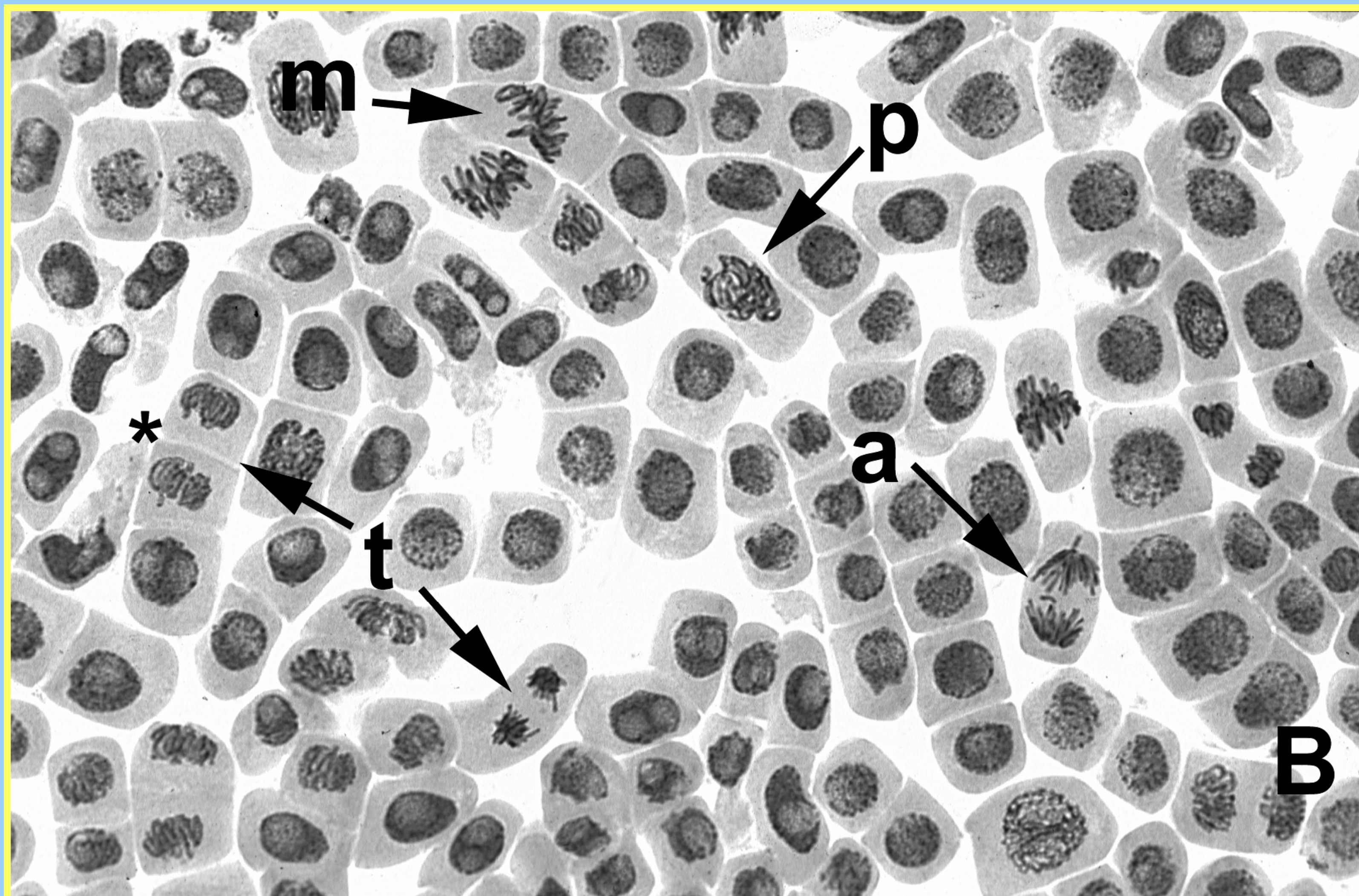
1,8-cineole



1,4-cineole

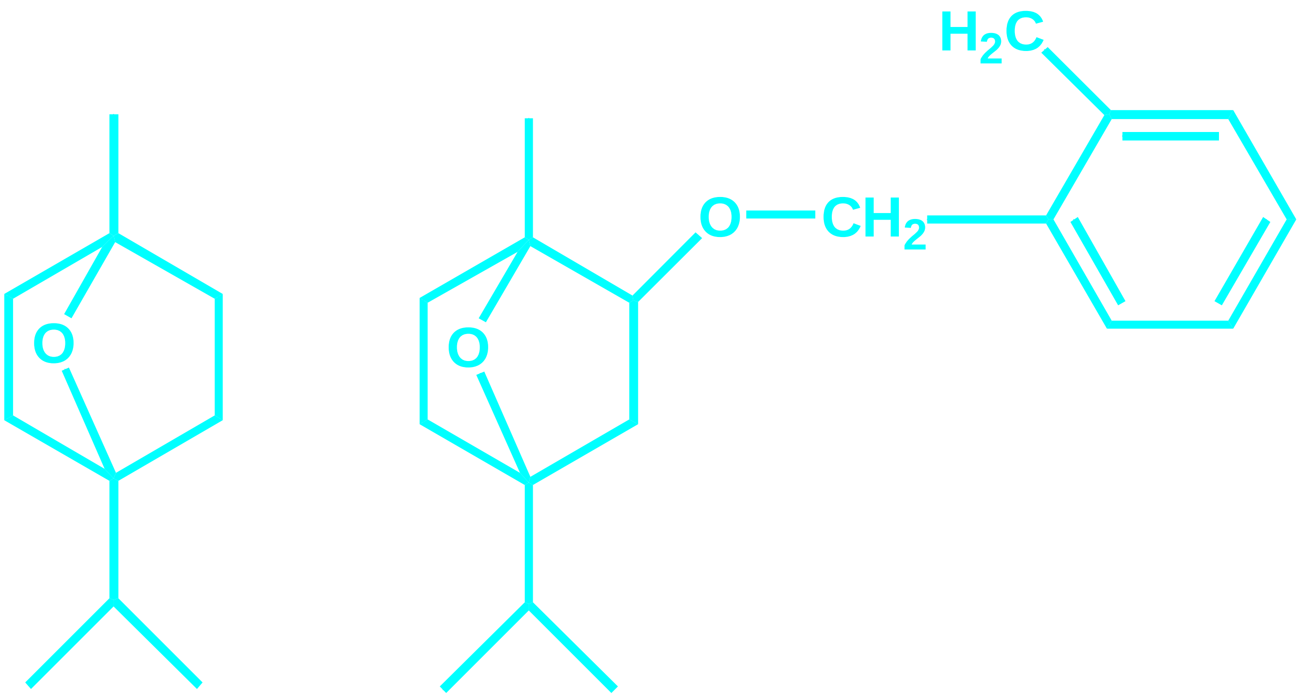
S. O. Duke, 2002

1,4-cineole



Duke, 2002

1,4-cineole (A) & cinmethylin (B)

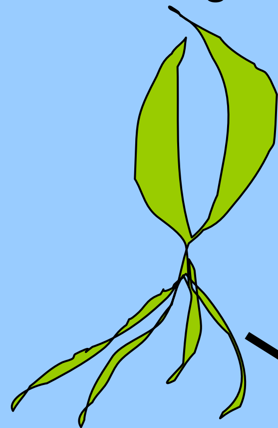


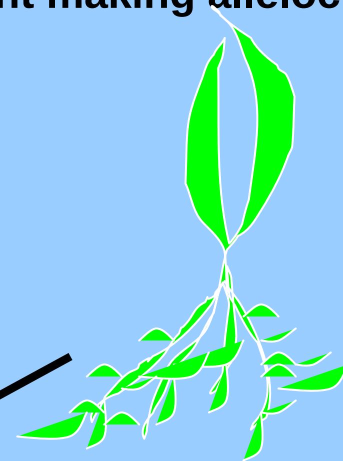
A

B

Duke, 2002

Plant not making allelochemical | **Plant making allelochemical**





Extract mRNA

↓

Differential display or subtractive hybridization to determine differences in gene expression

↓

Clone identified genes

↓

Sequence genes and compare with databases

Transform plant with antisense or overexpression constructs to determine gene function

Express genes to determine function of gene product

↓

Identification of proper gene(s) for crop transformation

S. O. Duke, 2001

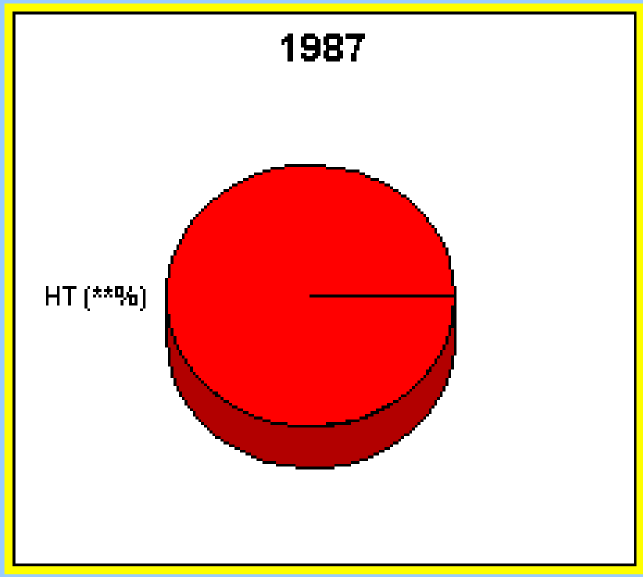
Herbicide-resistant crops

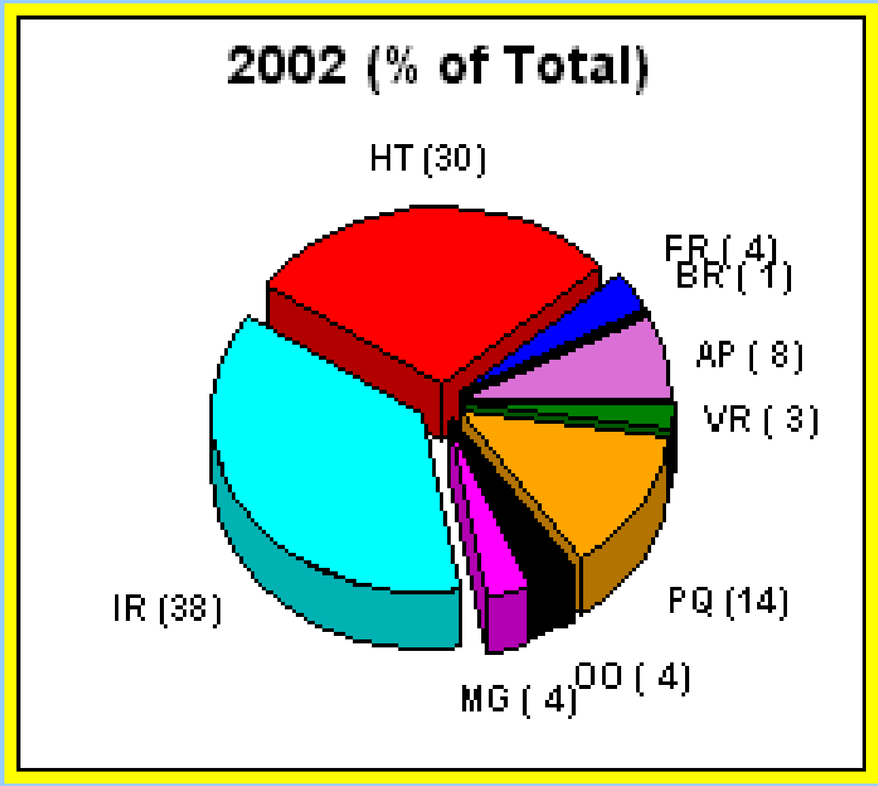
Rapid developments in biotechnology have promoted the development of genetically modified crop plants.

Herbicide-resistant crops (HRCs) dominate alongside those that are insect- or disease-resistant.

There are many advantages in the use of HRCs, but the relatively fewer disadvantages are so serious that they may upset all of that.

Biotechnology-derived pesticide resistant crops





1987 till present

S. O. Duke, 2002

Herbicide-resistant crops available in North America

Herbicide	Crop	Year available
Bromoxynil	cotton	1995
	canola	2000
Cyclohexanediones (sethoxydim)*	maize	1996
Glufosinate	canola	1997
	corn	1997
Glyphosate	soybean	1996
	canola	1996
	cotton	1997
	maize	1998
Imidazolinones*	maize	1993
	canola	1997
	wheat	2002
	rice	2002
Sulfonylureas*	soybean	1994
Triazines*	canola	1984

*not transgenic

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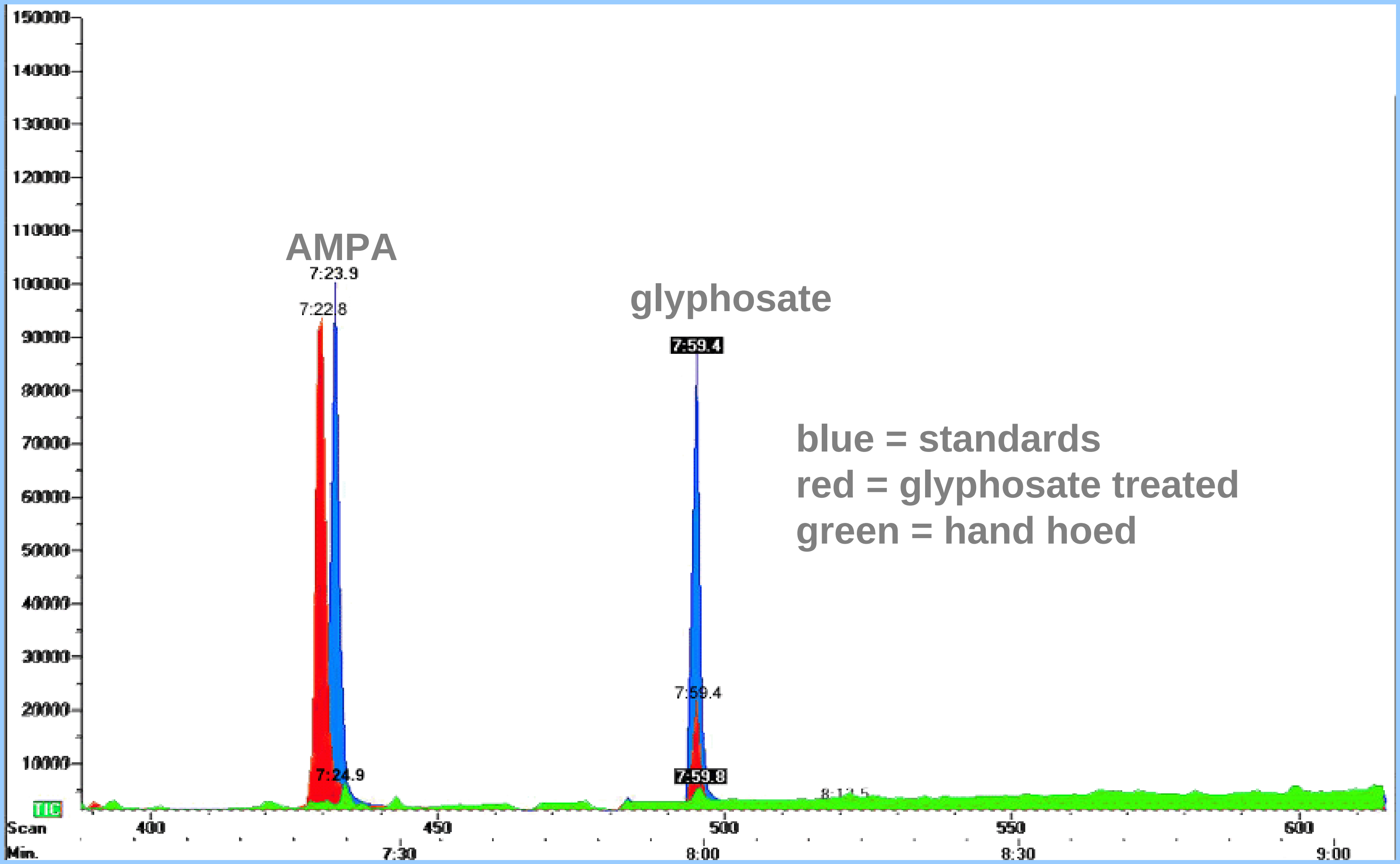
GS/MS



S. O. Duke, 2002

Advantages of HRCs can be summarized as broad-spectrum weed control and favourable cost-benefit ratios.

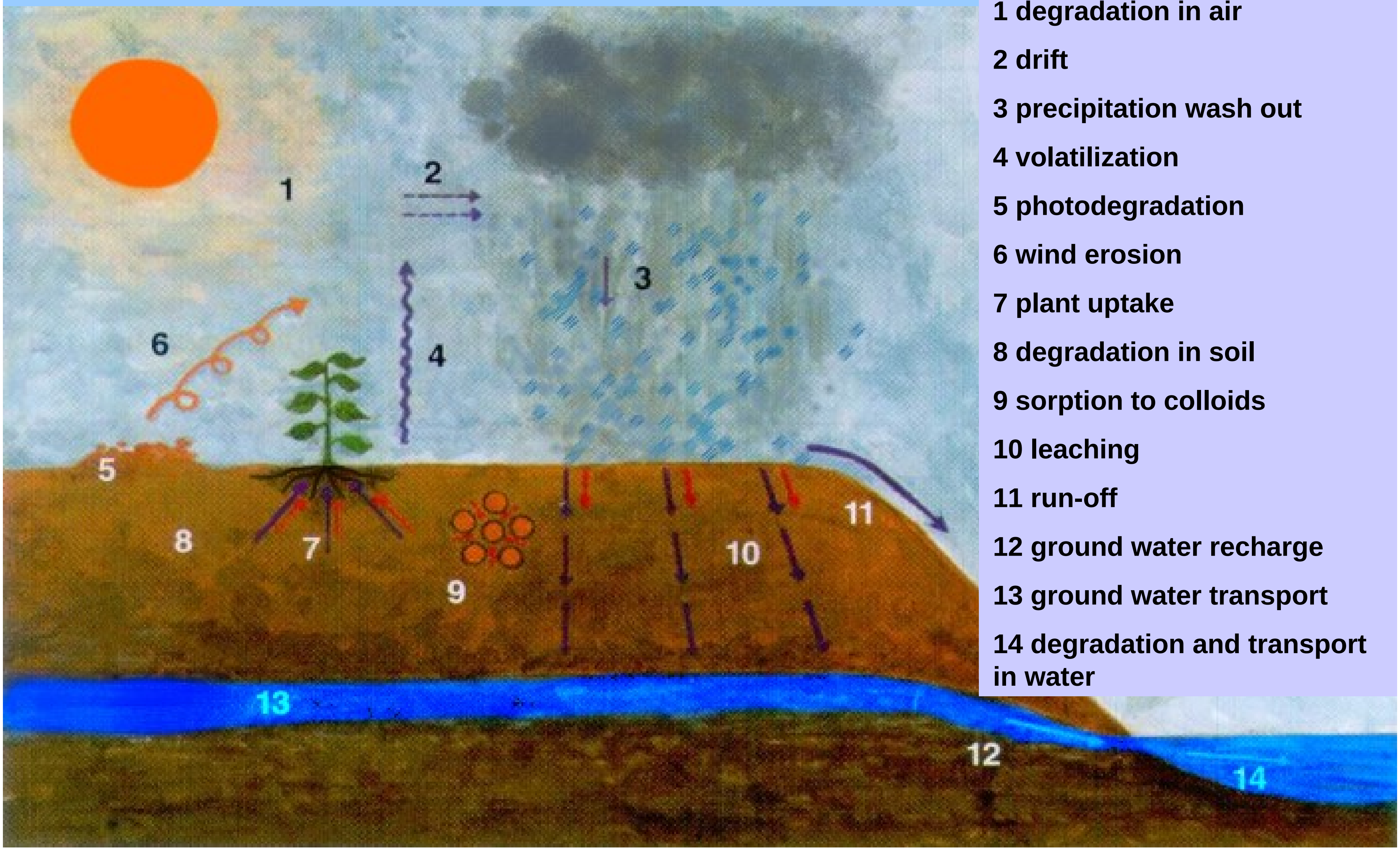
Potential and real **disadvantages of HRCs** are:

- The HRC itself may become a weed (r)
- Selection of resistant weeds (r)
- Shifts in weed flora to those that are tolerant (r)
- Cross-breeding between related species (p)
- High use-levels lead to environmental pollution (p)

Constraints for chemical control

- Growing public concern about pesticides in the environment.
- Weed species that are resistant to herbicides are on the increase.
- Development of new chemistry has slowed down.

Pesticide fate in the environment



1 degradation in air

2 drift

3 precipitation wash out

4 volatilization

5 photodegradation

6 wind erosion

7 plant uptake

8 degradation in soil

9 sorption to colloids

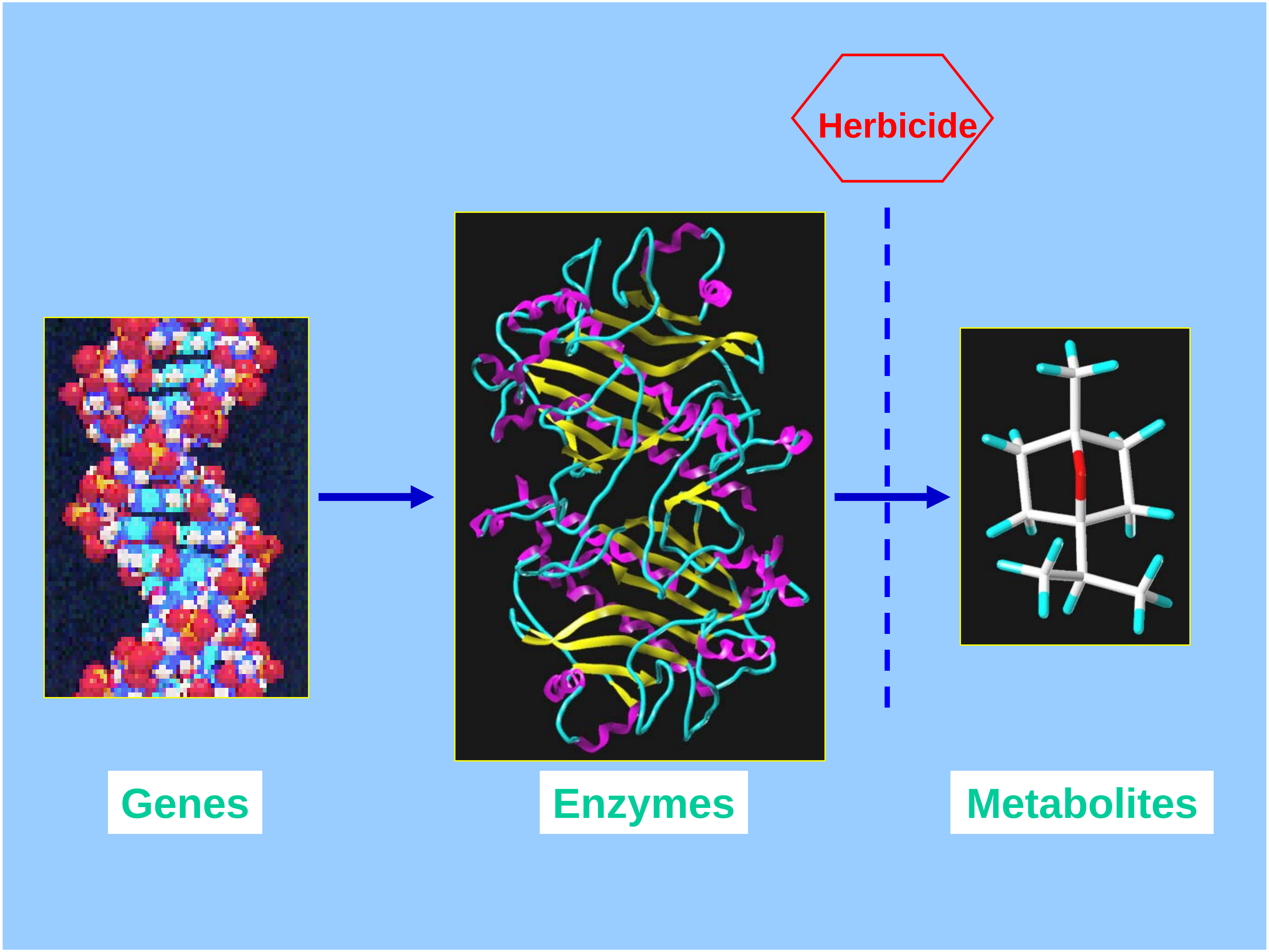
10 leaching

11 run-off

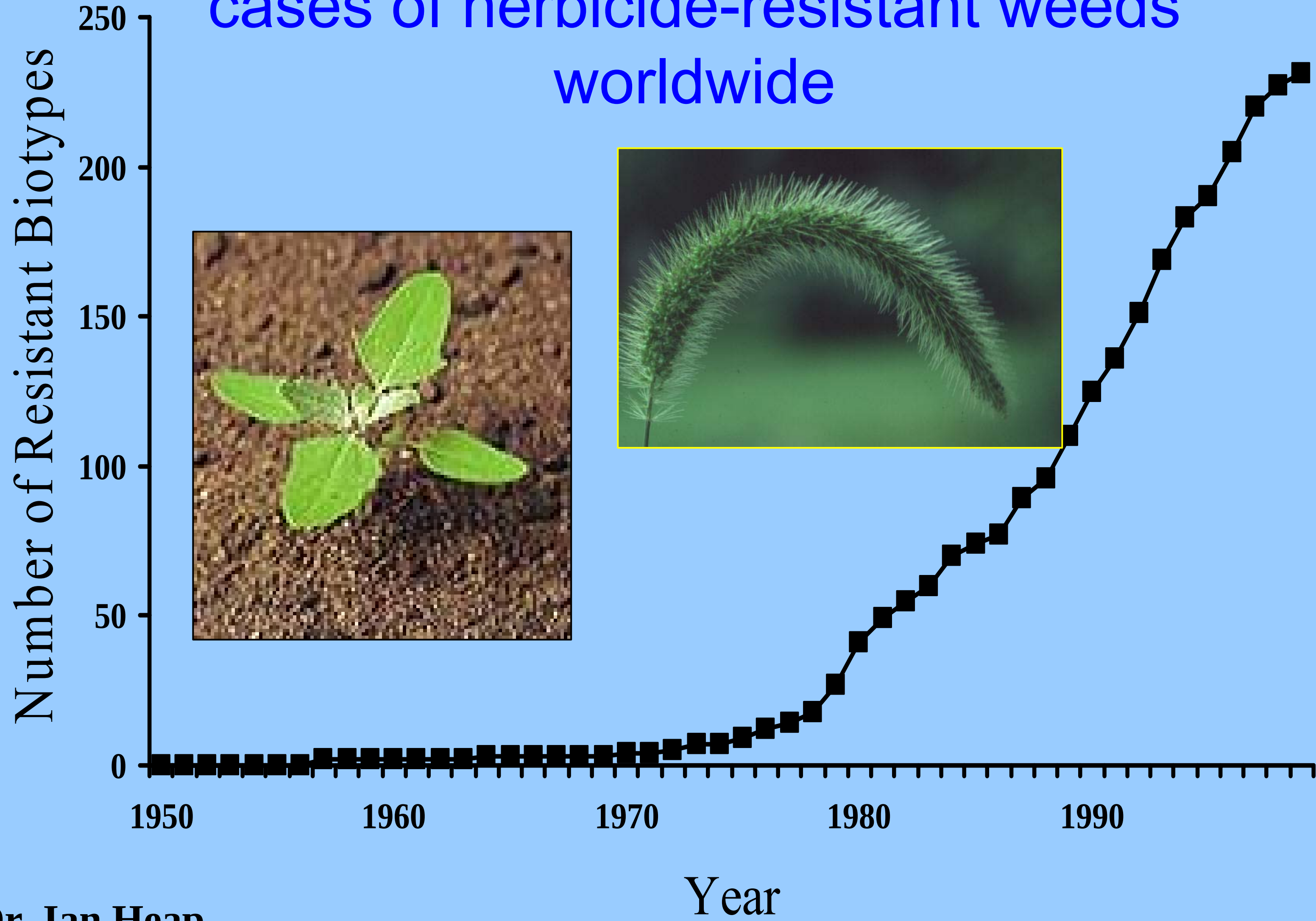
12 ground water recharge

13 ground water transport

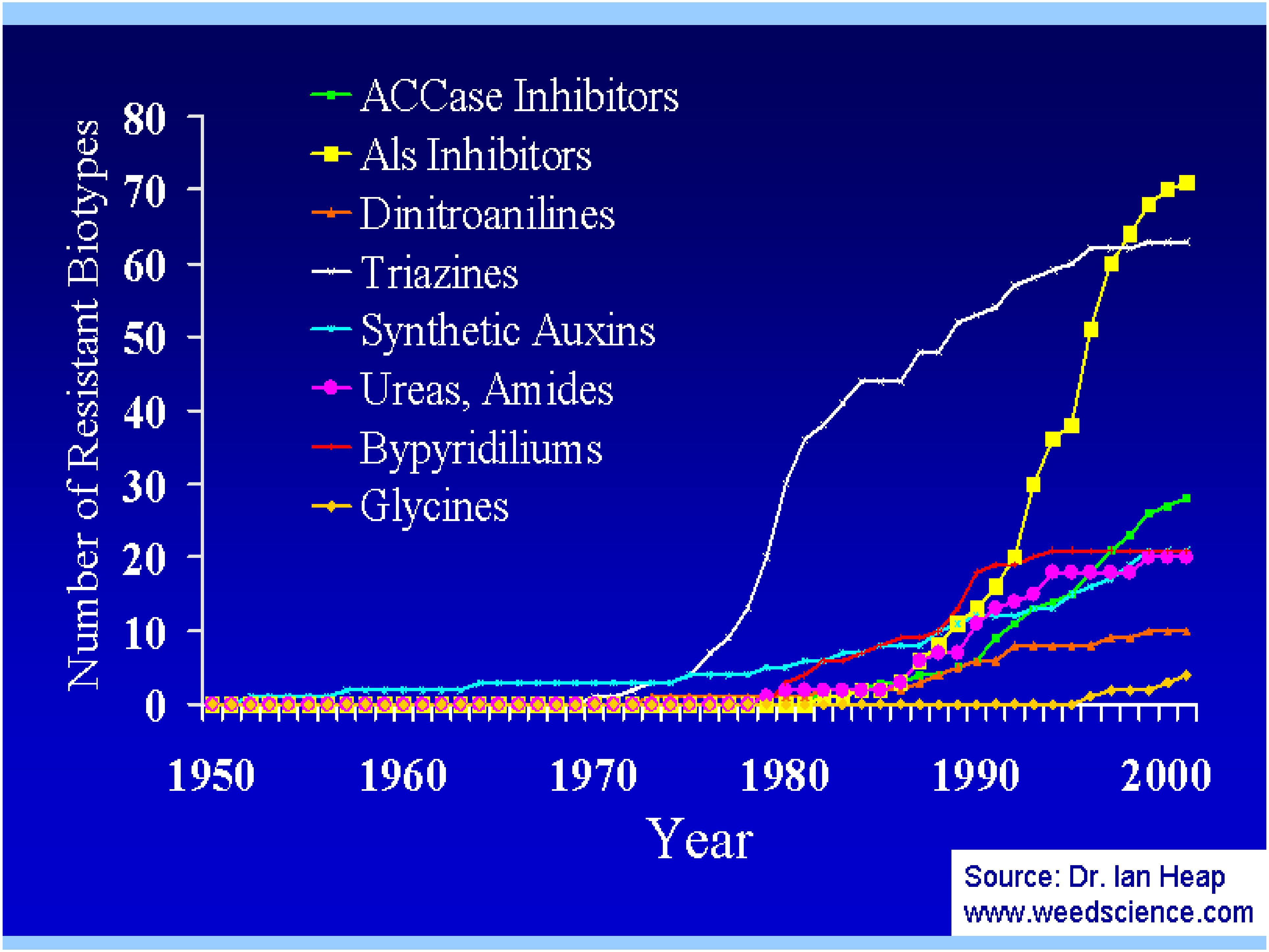
14 degradation and transport in water


Herbicide
Genes
Enzymes
Metabolites

The chronological increase in unique cases of herbicide-resistant weeds worldwide



Dr. Ian Heap
www.weedscience.com


ACCase Inhibitors
Als Inhibitors
Dinitroanilines
Triazines
Synthetic Auxins
Ureas, Amides
Bypyridiliums
Glycines
Number of Resistant Biotypes
80
70
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
Year
Source: Dr. Ian Heap
www.weedscience.com

Lessons learned, or rather, re-learned

"In weed control there is no technology, however powerful, that provides permanent solutions." (Hurle, 1998)

"It is necessary to ensure a certain amount of diversity in weed control measures, so that problems associated with excessively one-sided use of a single method can be put right or prevented."

Because nature involves a myriad of processes that are complexly linked, nothing in it occurs in a void; therefore, it is futile to hope for total external control over even a single life form in the medium- or long-term.

CONCLUSION

Greater use of technology for weed control will be made in future, and it will be simpler for the user.

Herbicide-resistant crops will increase the dominance of chemical weed control still further.

Public concern and regulatory restrictions placed pesticides will drive technology towards the lower risk options.

Lower risk options will strive to meet fundamental requirements of “sustainable agriculture”.

Future agricultural practices will be more technology-dependent in order to ensure food security, safe food and a protected environment.

Futuristic view of weed control

- Genetic modification

  Crops with natural defenses (allelochemicals) against weeds.

  Less virulent weeds.

  More virulent biocontrol agents.

- Herbicides

  Herbicides from natural products (e.g. allelochemicals).

  Herbicides with multiple mechanisms of action.

Research focus areas in the Department

Sustainable crop production

Optimization of the plant* x environment interaction by means of irrigation, nutrition, weed management, growth manipulation, etc.

Plant-, soil-, water- and environment

Studies on plant* water-use efficiency, drought-tolerance, etc.

Causes and remediation of chemical and physical deterioration of soils.

Rehabilitation of disturbed sites.

* = Plants with economic value = grain and vegetable crops, pastures, ornamentals, fruit crops, medicinal and essential oil plants.

ACKNOWLEDGEMENTS

"It is the human mind and its creation, technology, which has explored and made this immensity known to us.

If we are somehow compelled to feel humbled before all this, we should also feel humble before those among us who have so expanded our horizons."

– Degregori (2001)