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Phytomanagement of contaminated land: science, technology and context

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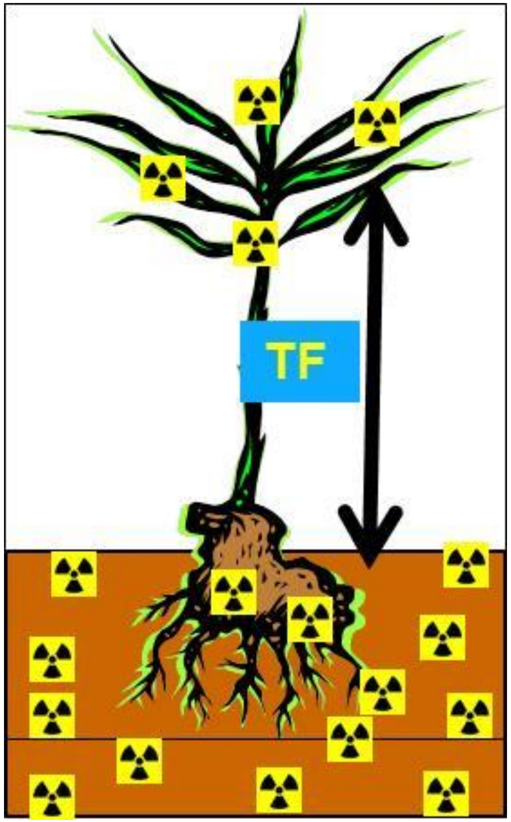
The complexity of contaminated land management

Criteria for a successful remediation strategy

Requirements and classification of contamination that requires remediation	Effectiveness of technology options	Constraints on implementation for each technology	Wastes generated in each step of remediation, respective waste management options and their availability
Doses received during implementation	Side-effects each technology might have	Cost/benefit considerations	Stakeholder opinion

Phytomanagement based countermeasures aim at limiting transfer to food chain

$$Transfer\ factor\ (TF) = \frac{Concentration\ in\ crop\ (\frac{Bq}{kg})}{Concentration\ in\ soil\ (\frac{Bq}{kg})}$$

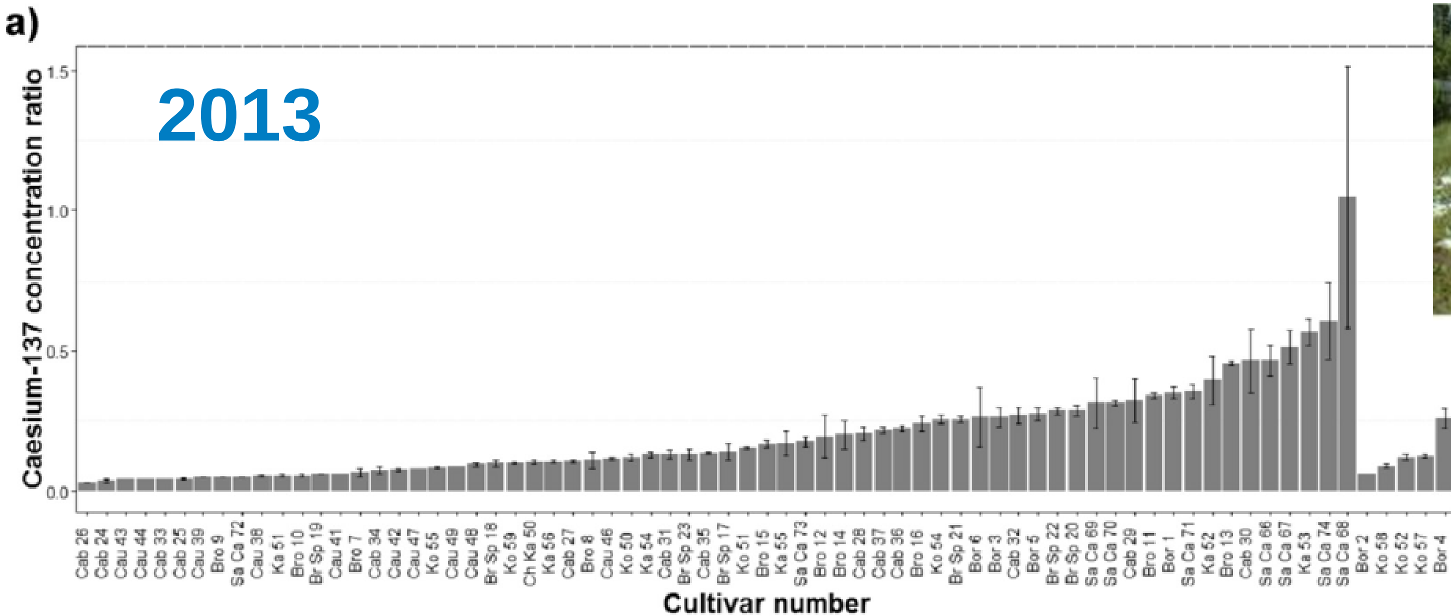


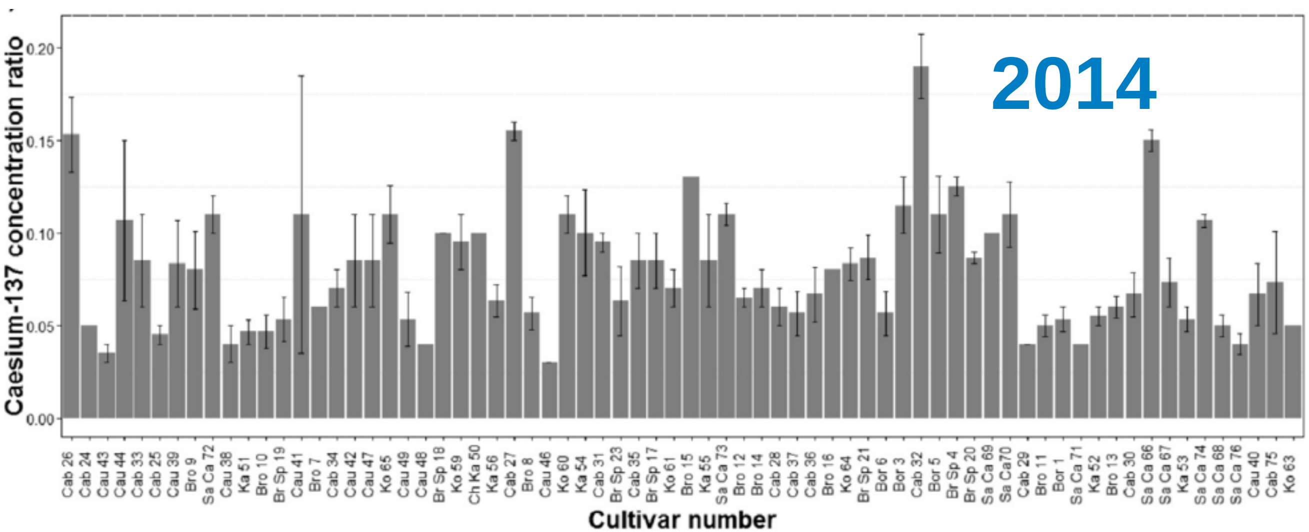
Countermeasures aimed at limiting transfer to food chain
Crop selection

Change	Reduction factor	Social and economic consequences
Other varieties of same crop	Up to 2-4	Very low
Other but comparable crop	Up to 2-3	Low
Green vegetables to cereals	Up to factor 5	High
Cereals to edible industrial crops, e.g. oil seeds, sugar beet	> Factor 10	Low
Cereals to non-edible industrial crops, e.g. flax	Factor 10 - 100	Low ↔ High
Radical improvement of meadows and pastures	Factor 2-10	Low
Arable or cattle system to forestry	>> Factor 100	Extremely high

Sources: STOTEN, 1993,137,169-172; Euranos datasheets

Other varieties of same crop:
35-fold variation in transfer factor for c 70 Brassica species





5 species with persistently lower TF

Source: Penrose et al. JER 2016 Cultivar substitution as a remediation strategy in radiocaesium and radiostrontium contaminated areas

Alternative crop usage - Food crops as fodder

- For lifestock feed: threshold limit of 100 Bq/kg as for food
  - Psychologically likely more acceptable to give contaminated fodder to animals than to give "contaminated" food to people.

Nobuoka (2015):

"for areas that have suffered important radioactive contamination radioactivity levels in unhulled grains of fodder rice to be below the 100 Bq/kg limit (after zeolite and K-application), so that rice is usable as livestock feed"

Source: S. Nobuoka, 2015, The Potential for Producing Rice for Feed and Whole-Crop Rice Silage in Radiation- Contaminated Areas, T. Monma et al. (eds.), *Agricultural and Forestry Reconstruction, After the Great East Japan Earthquake*, DOI 10.1007/978-4-431-55558-2_9

PHYTODECONTAMINATION: A persisting myth

Natural News.com

Phytoremediation: You can grow plants that help eliminate radiation in the soil

Sunday, June 19, 2011 by: J. McDonough-Horton

TUESDAY, 9 AUGUST 2011

Sunflowers may heal Fukushima's radioactive soil

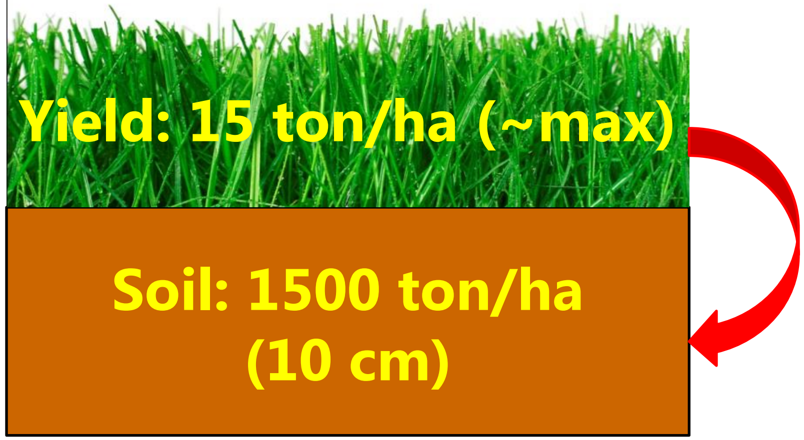
In Fukushima, Sunflowers Sow Hope For A Radioactive-Free Future

The agriculture ministry is also testing how well plants can clean the soil in highly contaminated areas, and several non-governmental organizations have followed suit with a campaign of sunflower planting. Nakanishi says that the effort is "nonsense", arguing that such phytoremediation would absorb only small amounts of radioisotopes. Chihiro Inoue, an expert in soil and groundwater remediation at Tohoku University, says that phytoremediation is worth testing, but warns that even if it works, "you're still left with the problem of how to dispose of the [radioactive] plants".

Annual crop off-take with harvest, << 1 %

Annual removal (%) $= \frac{C_{plant} \times yield}{C_{soil} \times W_{soil}} * 100 = \frac{TF \times Yield}{W_{soil}} * 100$

TF: 0.001-1



Yield/W_{soil}=0.01

Annual removal (%) with crop < 0.001 – 1%

"Annual Removal" of ^{137}Cs by physical decay: ~3 %

Some phytodecontamination examples from Japan

- IAEA* reported on 2011 phytodecontamination field studies → 0,05 % of soil Cs-137 phyto-extracted

- Phytoremediation of radiocesium in different soils using cultivated plants**
  - Four species of plants (sunflower, sorghum, amaranth, and buckwheat) and 2 soils
  - Highest extraction potential with amaranth, <u>≤ 1% extracted</u>
    - light-colored andosol: 0.013– 0.93% extracted
    - gray lowland soil: 0.007–0.038% extracted




* IAE A (2011) - International mission on Remediation of large contaminated areas off-site the Fukushima Dai-ichi NPP), Oct 2011
Suzuki, Saito, Tsukada, web-view 2016, http://www.rri.kyoto-u.ac.jp/anzen_kiban/outcome/Proceedings_for_Web/Topics_3-06.pdf

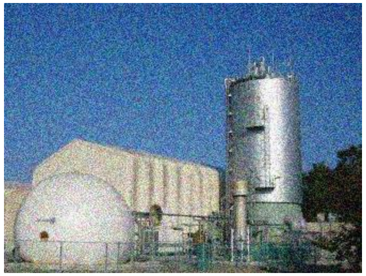
Other considerations for phytoextraction

- Lower extraction potential expected
  - Ageing → expected decline in TF and hence phytoextraction efficiency with time
  - If high TF, generally low biomass
  - Yield = 15 ton dw/ha = ~max yield
  - → also genetic engineering will not make phytodecontamination feasible
- Waste
  - Transport
  - Large volumes of wastes generated
- High input
  - Phytoextraction demands yearly crop establishment for many years
  - High yields will require adequate land management (fertilizer etc.)
  - There should at least be some revenue from crop harvested

Incineration facilities for crop residues tested at a demonstration site in affected areas

Alternative land use in areas where food production is jeopardized

- Biofuel crops
  - Biogas through fermentation of contaminated biomass
  - Combustion
    - Contaminated wood, willow, miscanthus, ..
  - Liquid biofuels
    - Biodiesel from rapeseed, bioethanol from sugar beet…
- Fibre crops
  - For rope, paper, isolation material,
  - Hemp, flax, Ramie…

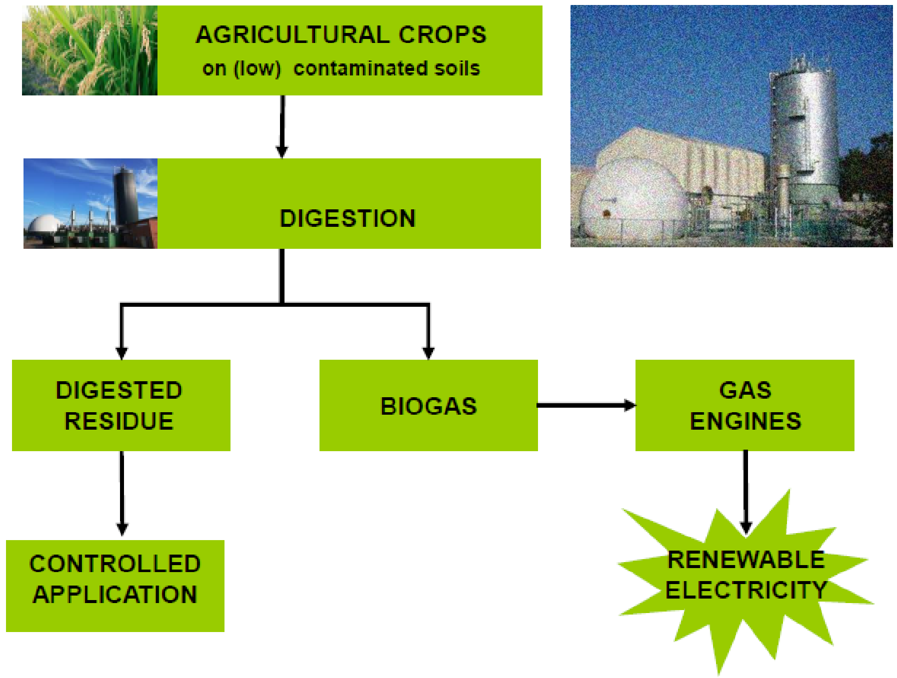


When high land pressure, alternative crops generally not too developed

Way to put contaminated land to (some) value

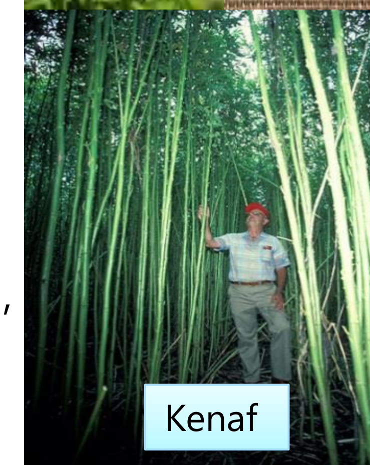
Biofuel crops

- Combustion/gasification
  - Higher energy efficiency than liquid biofuels, but best dried biomass
  - Scrubbing of off-gasses, activity concentrated in ashes
  - e.g. willow short rotation coppice, miscanthus, …
- Liquid biofuels
  - Bio-ethanol (e.g. sugar beet, wheat, s sorghum)
  - Bio-diesel (Rapeseed Oil)
  - Not competitive
- Fermentation
  - Wet biomass, clean off-gas



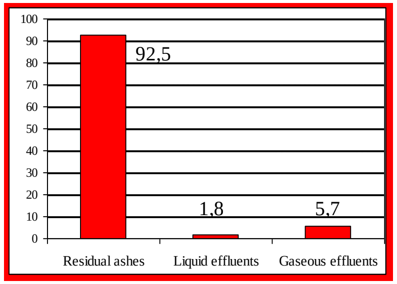
Fibre crops can be used for many things

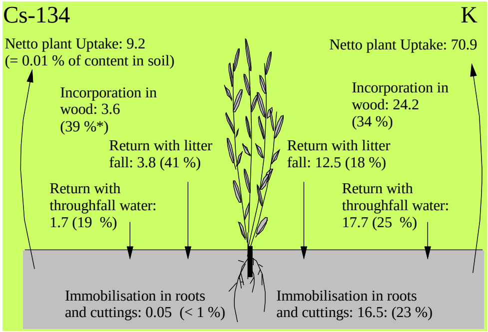
- Industrial hemp (*Cannabis sativa*)
  - Paper, clothing, rope, isolation and building material, kitten-tray, …
  - Hempseed oil: detergents, soaps, cosmetics
  - Cultivation restricted in Japan
- Jute fiber (e.g. *Corchorus capsularies*)
  - Curtains, chair coverings, carpets, area rugs, hessian cloth, and backing for linoleum
- Kenaf (*Hibiscus cannabinus*) (Res@Kochi Univ)
  - Rope, twine, coarse clothes, insulation material, … (+ renewable energy)
  - Kenaf seed oil used for cosmetics, industrial lubricants and for biofuel production
- Ramie (*Boehmeria nivea*)
  - Industrial sewing thread, packing materials, fishing nets, and filter cloths
  - Plant-derived ecological bioplastics (Toyota Prius)



For evaluating feasibility of alternative landuse: Holistic approach required

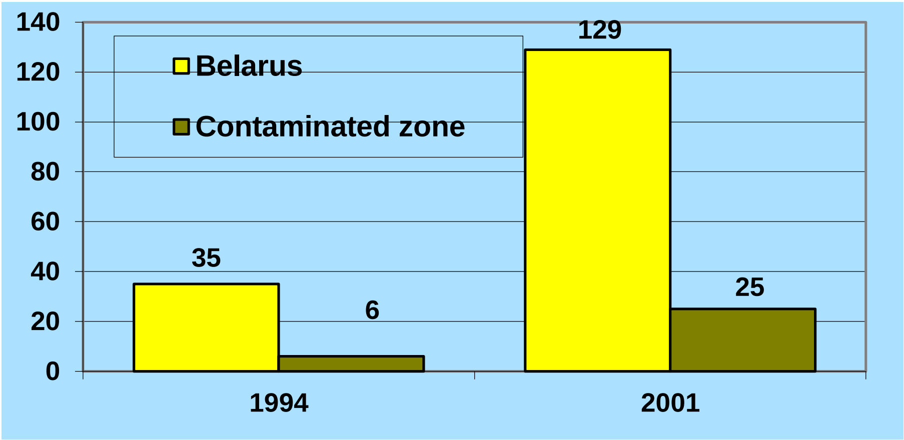
- Radioecology
  - Uptake and fate during production and conversion (waste, end product)
  - ~OK for willow SRC and biofuel crops, hardly any info for fibre crops
- Dosimetry
  - Dose during crop production, conversion, transport and waste management
- Agricultural feasibility
  - Crop requirements, crop cultivation requirements
- Conversion facilities
- Economics
  - Production, conversion, waste disposal
- Public acceptance
  - e.g. familiarity with culture, loss of confidence in end products



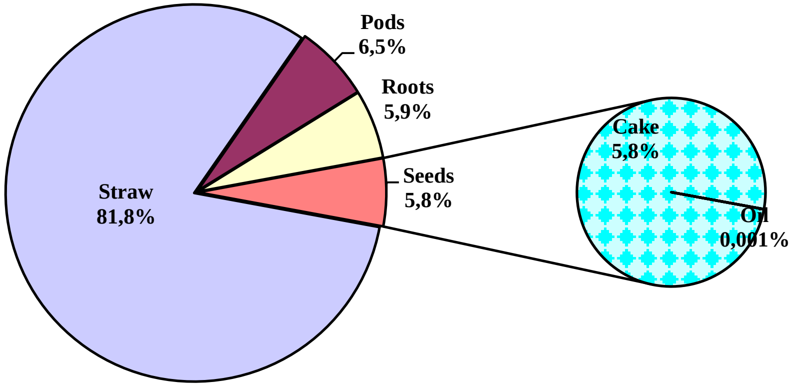


Alternative (energy) crops in Chernobyl affected area

- Refining process of rapeseed/sunflower/flax crude oil into edible oil is an ordinary technology, but the radionuclides are removed from oil.
- Also applies to processing of grain into flour (flour/bran) or production of sugar (sugar/ press cake) from sugar beets or bioethanol (ethanol). Most radionuclides retained in secondary product or by-product.
- Production of rapeseed and processing to edible rapeseed oil are profitable technologies



Sowing areas of rapeseed in Belarus (thousand ha).



Sr-90 allocation in spring rapeseed biomass

Source: *IAEA-EC study* on the use of "Alternative Biodiesel Sources in Relation with Soil Decontamination" conducted by GOPA with BRISSA
I. Bogdevitch, Yu. Putyatin, C. Rigney, A. Chupov Edible Oil Production from Rapeseed Grown on Contaminated Lands/ Innovation Forum, Value chains in the processing of renewable raw materials", 10-11 December 2001, Gardelegen, Germany, 2001, p. -148-156.

Potential of using Chernobyl affected land for biofuel production in Belarus

Advantages

- 5.5 thousand hectares of contaminated land suitable for biofuel crops
- Available technological capacity for production of biodiesel
- Domestic and international market potential
- Potential to meet the sustainability criteria established by the EU

Disadvantages

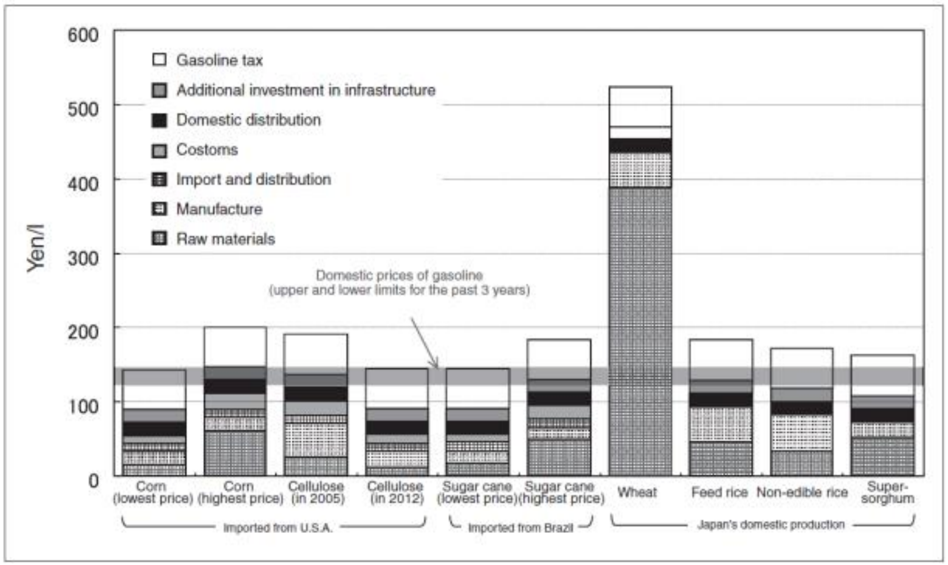
- Negligible land wrt expressed needs
- High cost land preparation and fragmentation
- Disfavor from Ministry of Agriculture, Ministry of Emergency Situations
- Difficulties in disposing contaminated wastes
- Potential for worker exposures.
- Unfavorable economic costs

Source: UNEP – 2012 - Assessment of Environmental, Social and Economic Impacts of Biofuels in Belarus

Biofuel crops so far not much developed in Japan

- Japan: only 40 % self-sufficiency in food → 4.4 Mha arable land of which only 0.27 Mha is unused → Japan has limited inclination to establishment of biofuels

Local biofuel prices not competitive



Rapeseed production ↓ after 60s

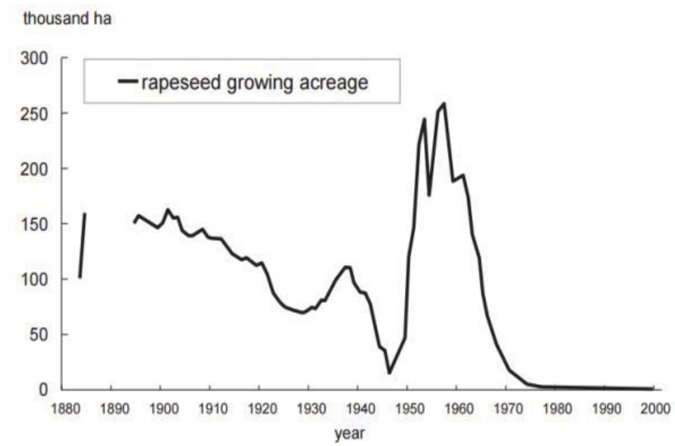
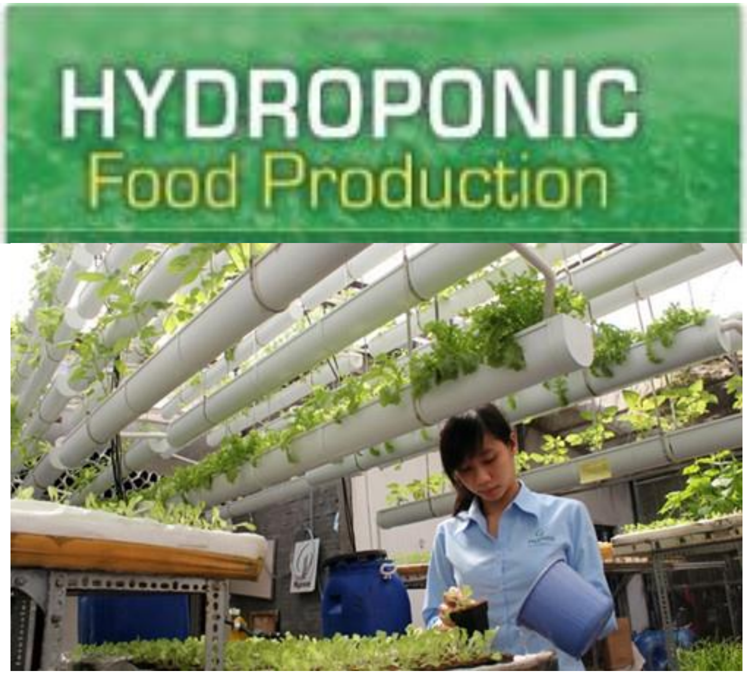


Fig. 1. Trend in rapeseed growing acreage
Source: Ministry of Agriculture and Fisheries (MAF) *Handout of Soy and Rapeseed* (*Daizu·Natane ni kansuru Shiryou*) (1965), MAF, Ministry of Agriculture Forestry and Fisheries (MAFF) *Crop Statistics* (*Sakumotu Toukei*) (each year)

- Rapeseed to remediate Tsunami affected land

Source: Sci Technol Trends, 2007, Quat Rev 25, 50-72

Non-soil based (phyto)-management options



Dual Harvest

Dual harvest
(Image: Rob Gilhooly)

Mushroom farm

Socio-economic and policy aspects of remediation

- Post-accident recovery is a technically intensive issue
  - Involves scientific and societal uncertainties, differing risk perceptions, disagreement among experts and societal trust issues.
- Consideration of factors aside from radiological and feasibility criteria
  - Acceptability of countermeasures, ethical and environmental considerations, spatial variation and the contrasting needs of people in urban, rural and industrial environments are important as well.
- Need to involve stakeholders
  - Benefit of involving stakeholders in recovery activities highlighted by accidents
- Overall feasibility of countermeasures
  - Often affected by the perception of end-users related to the (faintest) presence of radionuclides in end products even if not intended for human consumption (e.g. biofuel, fibre).

Overall conclusions

- Continued effort to identify sustainable ways to valorize affected areas and revive the economic potential
- Countermeasures have to be sustainable and need to lead to profitable or self-sufficient production of produce with low radionuclide contamination.
- Phytomanagement options
    - Can be optimised as e.g. in crop species selection for very low uptake and high yields.
    - Alternative land uses are potential approaches to revitalise contaminated agricultural land but require holistic study
    - Non-soil (direct) based phytomanagement approaches (green houses – soil or aquaculture) are high-potential new venues for contaminated land recovery.