Penrose, B.; Johnson née Payne, K.A.; Arkhipov, A.; Maksimenko, A.; Gaschak, S.; Meacham, M.C.; Crout, N.J.M.; White, P.J.; Beresford, N.A.; Broadley, M.R. 2016. **Inter-cultivar variation in soil-to-plant transfer of radiocaesium and radiostrontium in Brassica oleracea.** *Journal of Environmental Radioactivity*, 155-156. 112-121.
10.1016/j.jenvrad.2016.02.020

Inter-cultivar variation in soil-to-plant transfer of radiocaesium and radiostrontium in *Brassica oleracea*

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Abstract

Radiocaesium and radiostrontium enter the human food chain primarily via soil-plant transfer. However, uptake of these radionuclides can differ significantly within species (between cultivars). The aim of this study was to assess inter-cultivar variation in soil-to-plant transfer of radiocaesium and radiostrontium in a leafy crop species, *Brassica oleracea.* This study comprised four independent experiments: two pot experiments in a controlled environment artificially contaminated with radiocaesium, and two field experiments in an area contaminated with radiocaesium and radiostrontium in the Chernobyl Exclusion Zone. Radiocaesium concentration ratios varied 35-fold between 27 cultivars grown in pots in a controlled environment. These 27 cultivars were then grown with a further 44 and 43 other cultivars in the Chernobyl Exclusion Zone in 2003 and 2004, respectively. In the field-grown cultivars radiocaesium concentration ratios varied by up to 35-fold and radiostrontium concentration ratios varied by up to 23-fold.

In three of these experiments (one pot experiment, two field experiments) one out of the 27 cultivars was found to have a consistently lower radiocaesium concentration ratio than the other cultivars. The two field experiments showed that, five out of the 66 cultivars common to both experiments had consistently lower radiocaesium concentration ratios, and two cultivars had consistently lower radiostrontium concentration ratios. One cultivar had consistently lower radiocaesium and radiostrontium concentration ratios.

The identification of cultivars that have consistently lower radiocaesium and/or radiostrontium concentration ratios suggests that cultivar selection or substitution may be an effective remediation strategy in radiologically contaminated areas. Future research should focus on plant species that are known to be the largest contributors to human dose.

Keywords

Caesium, strontium, remediation, inter-cultivar variation, plant

1. Introduction

Radiocaesium and radiostrontium enter the human food chain primarily via soil-plant transfer (Ehlken and Kirchner, 2002). However, the concentration of these elements taken up by plants varies at the family (Broadley and Willey, 1997; Willey and Fawcett, 2006), species (Broadley and White, 2012) and cultivar scale (Payne et al., 2004; Penrose et al., 2015). Cultivar substitution, where a cultivar with higher uptake of an element is substituted for a cultivar with lower uptake of that element, is a possible method for reducing transfer of radionuclides to humans (White et al., 2003; Penrose et al., 2015). However, little is known about the extent and nature of variation in radiocaesium and radiostrontium uptake between cultivars (Beresford et al., 2006), and thus cultivar substitution has not been widely adopted as a remediation strategy. The authors are only aware of one study that has reported the use of cultivar selection as a remediation strategy; 2-3 fold reduction in ^{137}Cs and ^{90}Sr uptake by rapeseed was achieved by selecting varieties with lower Cs and Sr uptake (Fesenko et al., 2007). A recent review of inter-cultivar variation, considering a range of plant species, showed that caesium (Cs) and strontium (Sr) concentrations vary about 2-fold between the cultivars with the lowest and highest concentration ratios, although the literature reviewed predominately reported studies with fewer than 20 cultivars (Penrose et al., 2015).

The aim of this study is to assess variation in soil-to-plant transfer of radiocaesium and radiostrontium into a leafy crop species, *Brassica oleracea*. This species belongs to the Brassicaceae (mustard) family, which includes other important crop types such as *Brassica napus* (oil seed rape, swede), *Brassica rapa* (pak choi, turnip) and the widely-studied plant species *Arabidopsis thaliana*. Domesticated *B. oleracea* has a number of familiar crop types, including cauliflower and broccoli, cabbage, Brussels sprout, kohlrabi and kale which display distinctive morphological variation (Kennard et al., 1994). *B. oleracea* is an important vegetable and fodder species: global production of ‘cauliflowers and broccoli’ exceeded 22 million tonnes in 2013 (FAOSTAT, 2015); >420,000 tonnes of *B*. *oleracea* were produced in the UK alone in 2013/2014 (DEFRA, 2014).

There are numerous published studies on both inorganic and organic compositional traits in *B. oleracea*. For example, for leaf calcium (Ca) and magnesium (Mg) concentrations, which as Group II elements are likely to display similarities to radiostrontium in terms of uptake and accumulation, there was about 2-fold variation in shoot concentrations among 74 field-grown cultivars (Broadley et al., 2008). For potassium (K), which as a Group I element is likely to display similarities to radiocaesium, albeit to a lesser degree than among Group II elements (Broadley and White, 2012), there was 1.6-fold variation in shoot K concentrations among 72 field-grown cultivars (White et al., 2010). However, we have identified just one published study reporting (stable) Cs and Sr uptake by *B. oleracea* cultivars, in which a single Brussels sprout cultivar was compared to a single cabbage cultivar (Bibak et al., 1999). The Cs concentration of the edible portion differed between these two genotypes by 2.4-fold and Sr concentration varied by 4.2-fold. Whilst soil-to-human transfer of Cs and Sr via vegetable crops is unlikely to be the major pathway of these elements into the food chain based on typical 'Western' dietary habits with high consumption of animal products and cereals, the contribution of leafy vegetables to dietary intakes of Group I and II essential elements is significant (Broadley and White, 2010). For example, vegetables (excluding potato) are likely to contribute between 5 and 10% of dietary Ca, Mg and K intake in the UK. Therefore, if concentrations of these elements in vegetable crops is manipulated via plant breeding or agronomy, it can significantly affect dietary intakes (Broadley and White, 2010).

2. Materials and Methods

2.1 Overview of experiments

This study comprised four experiments. Experiment 1 aimed to characterise the time course of ^{134}Cs accumulation by *B. oleracea* under controlled conditions, to inform subsequent experiments of the number of days after sowing (DAS) for the harvest of a larger number of *B. oleracea* cultivars. Experiment 2 aimed to determine the ^{134}Cs concentration ratios (concentration ratio is defined as the quotient of the activity concentration in the shoot (kBq kg^{-1} dry weight (d. wt)) and in the soil (kBq kg^{-1} d. wt); see Equation 1) in a larger number of *B. oleracea* morphotypes and cultivars. Experiments 1 and 2 were conducted in a growth chamber and used a peat-based potting medium contaminated artificially with ^{134}Cs. In Experiment 1, shoot ^{134}Cs concentration ratio was determined in eight commercial cultivars of *B. oleracea*, between 21 and 118 DAS. As shoot ^{134}Cs concentration ratio remained relatively constant during growth, 40 DAS was chosen as a pragmatic time to assay the growth and ^{134}Cs concentration ratio of established *B. oleracea* plants in subsequent experiments. In Experiment 2, shoot ^{134}Cs concentration ratio was measured for a wider range of commercial cultivars of *B. oleracea* (*n*=27).

Experiments 3 and 4 aimed to determine variation in ^{137}Cs and ^{90}Sr concentration ratios under field conditions. In these experiments, shoot ^{137}Cs and ^{90}Sr concentration ratios were measured in up to 71 cultivars of *B. oleracea* at two different field sites in the Chernobyl Exclusion Zone, Ukraine, in 2003 (Experiment 3) and 2004 (Experiment 4). Field sites were selected for logistical reasons of access and ease of maintenance in each year and had contrasting soil ^{137}Cs and ^{90}Sr activity concentrations due to the heterogeneous nature of radionuclide deposition following the accident at the Chernobyl Power Plant in 1986. The raw results from Experiments 1-4 can be found in Tables S1-4.

2.2 Cultivars

Commercial *B. oleracea* cultivars were used in the experiments. The rationale for selecting panels of commercial *B. oleracea* cultivars is described in detail by Broadley et al. (2008). Briefly, seeds were selected to provide coverage of the major edible morphotypes of *B. oleracea* and included cultivars from the following varietas: *acephala* (kale), *alboglabra* (Chinese kale), *botrytis* (cauliflower), *capitata* (cabbage), *gemmifera* (Brussels sprout), *gongylodes* (kohlrabi), *italica* (broccoli), *sabauda* (savoy cabbage), and *sabellica* (borecole). Experiment 1 comprised one cultivar from eight varietas, whereas Experiments 2, 3 and 4 included between one and fifteen cultivars from eight or nine varietas (Table 1). All seed were obtained from commercial sources except for three accessions from Horticulture Research International Genetic Resources Unit (now Warwick Genetic Resources Unit) used in Experiment 3 (cultivars Ko 57, Ko 58 and Ko 62: Table S5). Commercial seed had typically been pre-treated with thiram (tetramethylthiuram disulfide) and/or iprodione (3-(3,5-dichlorophenyl)-N-isopropyl-2,4-dioxoimidazolidine-1-carboxamide) to reduce fungal contamination.

Table 1 Number of each of the nine morphotypes of *Brassica oleracea* grown in each of the four experiments

	Morphotype								
	Borecole *B. oleracea* var. *sabellica*	**Broccoli** *B. oleracea* var. *italica*	**Brussels sprout** *B. oleracea* var. *gemmifera*	**Cabbage** *B. oleracea* var. *capitata*	**Cauliflower** *B. oleracea* var. *botrytis*	**Chinese kale** *B. oleracea* var. *alboglabra*	**Kale** *B. oleracea* var. *acephala*	**Kohlrabi** *B. oleracea* var. *gongylodes*	**Savoy cabbage** *B. oleracea* var. *sabauda*
Experiment 1	1	1	1	1	1	1	0	1	1
Experiment 2	3	5	5	7	3	1	0	1	2
Experiment 3	6	10	7	14	12	1	6	9	9
Experiment 4	4	10	7	15	11	1	6	6	10

2.3 Experiment 1: Time course of ^{134}Cs uptake

Seeds of one cultivar of each of eight varietas (see Table S6) were sown at a density of three per pot at 0.5 cm depth in a well-mixed potting medium comprising 25% sand and 75% (v/v) compost (Shamrock medium grade sphagnum peat, Scotts UK, Bromford, Suffolk). Nutrients were incorporated in sufficient amounts per litre of compost to prevent deficiencies: NH_4NO_3 (0.4 g L^{-1}), KNO_3 (0.75 g L^{-1}), single super phosphate (P_2O_5, 0.225 g L^{-1}; 7% P) ground limestone ($CaCO_3$, 2.25 g L^{-1}), ground magnesian limestone ($CaCO_3.MgCO_3$, 2.25 g L^{-1}) and a trace element mixture containing B, Cu, Fe, Mn, Mo and Zn (WM255, Fargro Ltd, Toddington, Littlehampton, West Sussex, UK) at 0.4 g L^{-1}. The potting medium was characterised by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) using the methods described by Broadley et al. (2008). Water-soluble nutrients were added at the following concentrations per litre of water: 195 mg nitrate-N L^{-1}, 30 mg ammonium-N L^{-1}, 216 mg K L^{-1}, 63 mg Ca L^{-1}, 53 mg Mg L^{-1}, 30 mg Na L^{-1}, 5.5 mg P L^{-1}, 0.3 mg Fe L^{-1}, 0.06 mg Mg L^{-1}, 0.04 mg B L^{-1} and 0.03 mg Zn L^{-1}.

A solution containing 1 µM ^{133}Cs (a concentration typical of soil solutions; White and Broadley, 2000) as $^{133}CsCl$ and $^{134}CsCl$ at 17.76 kBq ^{134}Cs μmol^{-1} ^{133}Cs was prepared. Preliminary experiments had been conducted to determine an appropriate method to homogenise the distribution of Cs in the potting medium (Payne, 2005). The optimal method for incorporating the CsCl solution into the potting medium was to mix 1200 g compost; enough to fill four pots; and 800 mL of solution for 2 minutes in a large domestic food mixer (Kenwood KM310, Hampshire, UK). Pots were of dimensions 9 x 9 cm (top), 6 x 6 cm (bottom) x 10 cm (depth), and were filled with compost to 9 cm depth (compost volume=4812 cm^3 pot^{-1}, about 300 g compost). Pots were placed on a gravel tray in a growth chamber with illumination of 16 h d^{-1}. Temperature was maintained at 26°C (day) and 16°C (night) throughout the experiment.

The experimental design comprised an alpha-type randomised design (Patterson and Williams, 1976) of 256 pots, comprising 8 cultivars with 8 sequential harvests and 4 replicates per harvest. Due to uneven germination noted at 14 DAS, only two seeds per pot were retained in replicates one and two, and one seed per pot was retained in replicates three and four. To minimise the potential for soil splash and external contamination of plant surfaces, and also leaching and contamination of the growth chamber, pots were watered from below using deionised water, on alternate days.

Whole shoots were harvested destructively at eight times (21, 28, 33, 42, 49, 56, 75, 118 DAS), four replicate pots per time. Shoot fresh weight (f. wt) was determined in all samples. After harvesting, the compost from each pot was emptied out, mixed and a sample of approximately 5 g was taken from each pot. Shoot material and compost samples were oven dried for 72 h at 40°C. Dried shoot samples were weighed, and then ground using a domestic coffee grinder. Dried compost samples were placed into 20 mL scintillation vials for determination of ^{134}Cs activity concentration. Plant shoot and compost ^{134}Cs activity concentrations were determined for each sample by counting ^{134}Cs γ-emissions until the error decreased to 1.65 sigma or for a maximum of 60 minutes on an automatic well-type γ-counter (MiniaxiAuto-Gamma 5000 Series; Packard Instrument Company, Downers Grove, Illinois, USA). The detector of the γ-counter was normalised for ^{134}Cs according to the manufacturer's instructions and calibrated against results from calibrated hyper-pure germanium detectors. The background count rate was 64 counts per minute (± SE 2.6) when a blank tube or a tube filled with deionised water was present in the detection well and this activity concentration was subtracted from counts for each sample.

2.4 Experiment 2: Pot experiment

A total of 27 commercial cultivars of *B. oleracea* were grown (see Table S7), including the eight cultivars grown in Experiment 1 plus a further 19 cultivars which together comprised three borecole, five broccoli, five Brussels sprout, seven cabbage, three cauliflower, one kohlrabi, one oriental kale and two Savoy cabbage cultivars (Table 1). All growth conditions were identical to Experiment 1, except a radiolabel of 30 kBq ^{134}Cs μmol^{-1} ^{133}Cs was used. Two seeds were planted per pot and thinned to leave one seedling per pot at 14 DAS. Shoot f. wt, d. wt and ^{134}Cs activity concentration were determined for all plant and compost samples 40 DAS using the same methods as described previously.

2.5 Experiments 3 and 4: Field experiments in the Chernobyl Exclusion Zone

Two field experiments were conducted over two years. Experiment 3 (2003) and Experiment 4 (2004) included the 27 cultivars from Experiment 2, and an additional 43 (Experiment 4) or 44 (Experiment 3) cultivars from nine *B. oleracea* types (Table S5). Four of the cultivars used in Experiment 3 could not be used in Experiment 4 due to seed availability. These were replaced by three additional cultivars (Table S5).

2.6 Site description, experimental design and sowing

Both experimental sites were located in the Chernobyl Exclusion Zone in Ukraine (Experiment 3: 51.266422°N, Fig. 1; 30.225606°E; Experiment 4: 51.290662°N/E, 30.194946°E), where the soil was classified as having a ^{137}Cs deposition density of <185 kBq ^{137}Cs m^{-2} soil as a consequence of the Chernobyl accident in 1986 (Shestopalov, 1996).

Figure 1 Experiment 3 field site in the Chernobyl Exclusion Zone, Ukraine. Clockwise, from top-left: (i) and (ii) prepared soil beds (May 2003), (iii) Experiment 3 cabbages growing in late June, 2003, (iv) field site after harvest of Experiment 3 (August 2003); only ‘guard’ cabbages remain in the ground.

Soil ^{137}Cs and ^{90}Sr activity concentrations were measured in 2003 and 2004 for Experiments 3 and 4, respectively. However, other soil characteristics such as pH and clay content were not measured at this time. Therefore, soil was sampled and analysed further in May 2013 from the sites used for experiments in 2003 and 2004. To our knowledge, no cultivation activities had been undertaken on these sites during the intervening period. Soil pH, cation exchange capacity (CEC), concentrations of exchangeable P, K, Ca and Mg, organic matter and clay content were measured (Table 2; for details of the methods used, see Table S8).

The soil was cultivated using a hand-held rotavator to a depth of 15-20 cm and then hand-weeded. Soil beds were prepared prior to sowing and fencing was placed around the beds to minimise the risk of animal herbivory and for site security. Trickle irrigation pipes were laid on each bed, and connected to a water supply. Black and white polythene sheeting was used to cover the beds, to minimise both the re-suspension of soil particles and the re-establishment of weeds. Each experiment was laid out in a randomised block design of three replicates. These were allocated across five cultivation beds. Each bed comprised four rows of planting stations at 20 cm inter-row spacing. The outer two rows comprised guard rows of a cabbage cultivar. The inner two rows had 45 planting stations per bed. A small hole was cut into the polythene sheet at each planting station. Two seeds of the *B. oleracea* cultivars were hand-sown into each planting station. These seedlings were thinned to one plant per planting station at the 1-2 leaf stage. The plants were harvested 10 weeks after sowing in Experiment 3, and 13 weeks after sowing in Experiment 4.

2.7 Sample preparation and analysis

Shoots were cut above the polythene sheets, bagged and f. wt recorded. Topsoil samples (10 cm deep) were also taken from each plot using a soil auger. Shoots and soils were dried for

72 h at 40°C and dry weight was recorded. Soil and shoots were homogenised using a domestic coffee grinder. ^{137}Cs were determined using a high-purity germanium γ-spectrometer detector (Model GC3019, Canberra-Packard, Connecticut, USA). A standard source (OISN-16; Applied Ecology Laboratory of Environmental Safety Centre, Odessa, Ukraine) was used for calibration. The standard source contained epoxy granules (<3.0 mm) with the density of 1 g cm^{-3} with a ^{152}Eu specific activity of about 158 kBq kg^{-1} (as of 8 October 2001). The effectiveness of recording the 662 keV gamma line was 0.0206 pulse Bq^{-1} s^{-1}. The minimal detectable activity was 0.18 Bq per sample. Following homogenization, ^{90}Sr activity concentrations for the soil and plant samples were measured using a β-spectrometer (SEB-01-150, Atom Komplex Prylad, Kiev, Ukraine) with a thin-filmed (0.1 mm) plastic scintillator detector. This approach does not need any radiochemical pretreatment; the sample (approximately 2 g dry mass) was analysed as a solid matrix. The obtained spectra were processed by a correlation with measured spectra from the standard sources e.g. ^{90}Sr+^{90}Y, ^{137}Cs and ^{90}Sr + ^{90}Y, and ^{137}Cs combinations as well as from background measurements; the equipment was calibrated daily. A more detailed description of method can be found in Bondarkov et al. (2002, 2011) and Gaschak et al. (2011).

2.8 Data analysis

All data analyses were conducted using R (R Core Team, 2013). Concentration ratios were calculated using Equation (1) and inter-cultivar variation was calculated using Equation (2):

$$Concentration\ ratio = \frac{Activity\ concentration\ in\ the\ plant}{Activity\ concentration\ in\ the\ soil} \quad (1)$$

$$Inter-cultivar\ variation = \frac{Mean\ concentration\ ratio\ \ in\ the\ highest\ accumulating\ cultivar}{Mean\ concentration\ ratio\ in\ the\ lowest\ accumulating\ cultivar} \quad (2)$$

Activity concentration was measured in kBq kg^{-1} (d.wt) in all experiments.

Concentration ratios (as calculated using the above equation) are used throughout this paper. Using concentration ratios instead of concentrations minimises the effect of different concentrations of radiocaesium and radiostrontium in the soil of the different experiments. Where $\bar{x}$ is used, this represents the arithmetic mean.

3. Results

3.1 Soil characteristics

Characteristics of the soils from the sites for Experiment 3 and Experiment 4 are similar. The soils were slightly acidic (pH 6.2-6.4) and similar to most of the Chernobyl area (Davydchuk et al., 1994). The organic matter, clay content, exchangeable K, Ca and Mg were relatively low in comparison to agricultural soils in Western Europe.

Table 2 Soil characteristics for the experimental sites used in Experiment 3 and 4

Experiment	pH (H_2O)	Cation exchange capacity (mg-eq 100 g^{-1})	Exchangeable P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	Exchangeable Ca (mg-eq 100 g^{-1})	Exchangeable Mg (mg-eq 100 g^{-1})	Organic matter (%)	Clay content (%)
Experiment 3	6.2	11.2	107.8	51.8	2.66	0.47	1.5	7.6
Experiment 4	6.4	10	101.4	66.8	3.44	0.41	1.6	10.0

3.2 Experiment 1

Caesium-134 concentration ratios were relatively constant during growth (Fig. 2), decreasing by around 50% between Harvest 2 (28 DAS; $\bar{x}$=0.24) and Harvest 8 (118 DAS; $\bar{x}$=0.12). A harvest of 40 DAS was chosen for convenience for Experiment 2.

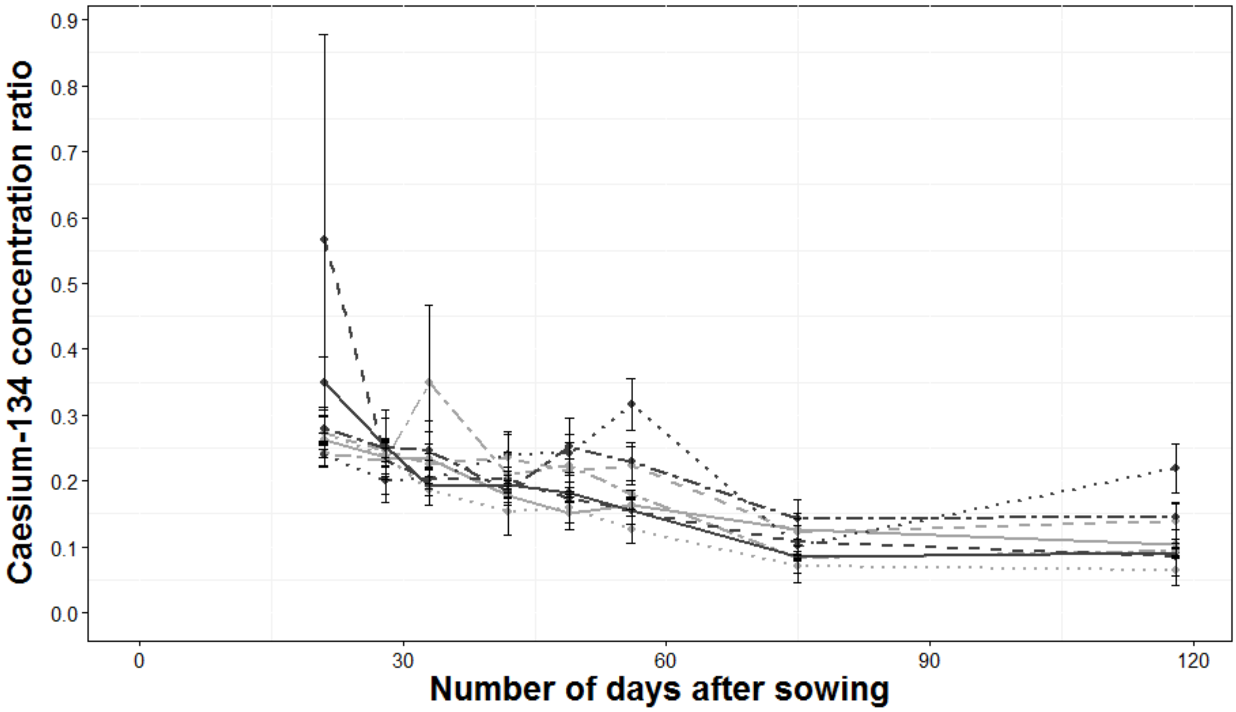


Figure 2 Mean shoot ^{134}Cs concentration ratio (in eight *Brassica oleracea* cultivars at harvest 21-118 days after sowing. - - - = Ch Ka 50; - - - = Bro 12; - — - = Sa Ca 69; - — - =Cab 31; ▪ ▪ ▪ = Ko 60; ▪ ▪ ▪ = Br Sp 21; — = Cau 41; — = Bor 4. Data are means (*n*=4) +/- standard error of the mean.

3.3 Experiment 2

The 27 cultivars varied 2.7-fold in shoot ^{134}Cs concentration ratio (Fig. 3). The highest concentration ratio was found in Bro 11 ($\bar{x}$= 0.65), and the lowest concentration ratio in BrSp 17 ($\bar{x}$= 0.24).

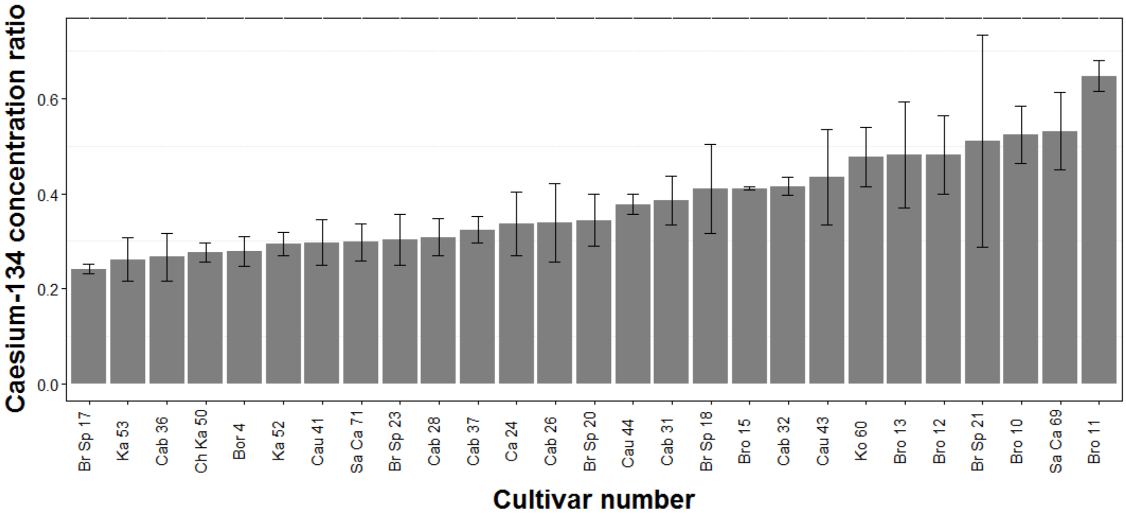


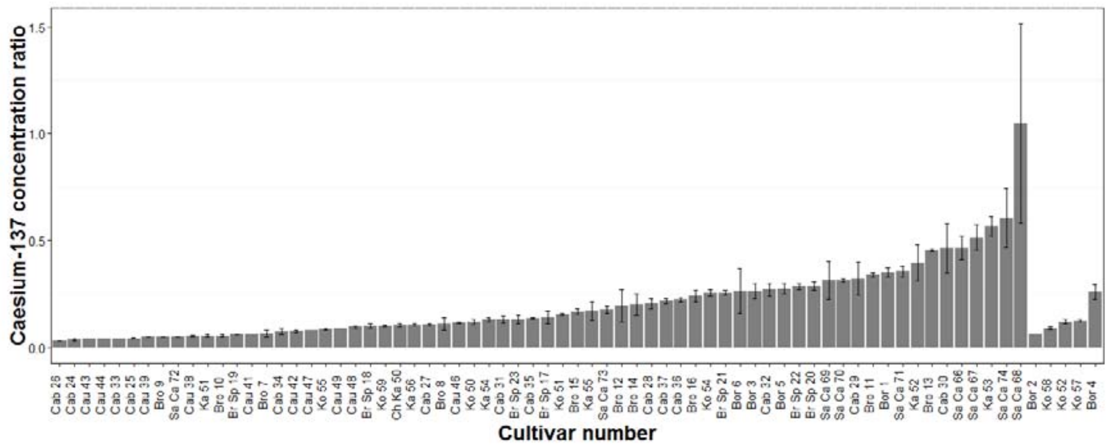
Figure 3 Mean ^{134}Cs concentration ratio for 27 *B. oleracea* cultivars from Experiment 2. Data are means (*n*=3) +/- standard error of the mean.

3.4 Experiment 3

Caesium-137 concentration ratios varied 35-fold in the 71 cultivars sampled in Experiment 3 (Fig. 4a). Cab 26 had the lowest mean ^{137}Cs concentration ratio ($\bar{x}$=0.03) and the highest concentration ratio ($\bar{x}$=1.05) was found in SaCa 68.

Ka 53 had the highest ^{90}Sr concentration ratio ($\bar{x}$=46) whereas the lowest ^{90}Sr concentration ratio was found in cultivar SaCa 72 ($\bar{x}$=2). The ^{90}Sr concentration ratio varied by 23-fold between the 71 cultivars.

a)



b)

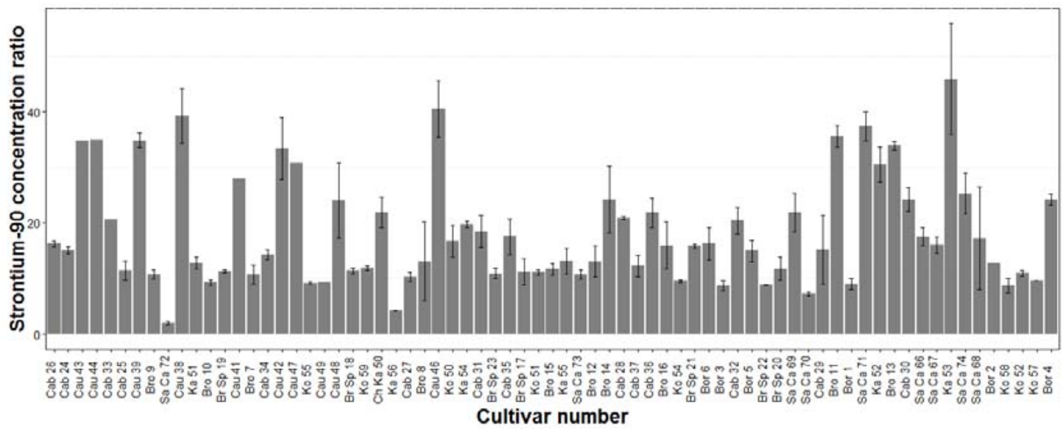


Figure 4 (a) Caesium-137 concentration ratios and **(b)** strontium-90 concentration ratios for 71 *B. oleracea* cultivars grown in Experiment 3. Cultivars studied in both Experiments 3 and 4 are ordered by their ^{137}Cs concentration ratio. Cultivars found only in Experiment 3 are added to the right of the cultivars studied in both experiments. Data are means (*n*=1-3) +/- standard error of the mean.

3.5 Experiment 4

Caesium-137 concentration ratios varied 5-fold between the cultivar with the highest CR (Cab 32, $\bar{x}$=0.16) and cultivar with the lowest CR (Cau 46, $\bar{x}$=0.03) studied in Experiment 4 (Fig 5a).

The ^{90}Sr concentration ratios varied 12-fold between cultivars studied in Experiment 4 (Fig. 5b). SaCa 70 had the highest ^{90}Sr concentration ratio ($\bar{x}$=129) and Cau 43 had the lowest ^{90}Sr concentration ratio ($\bar{x}$=10).

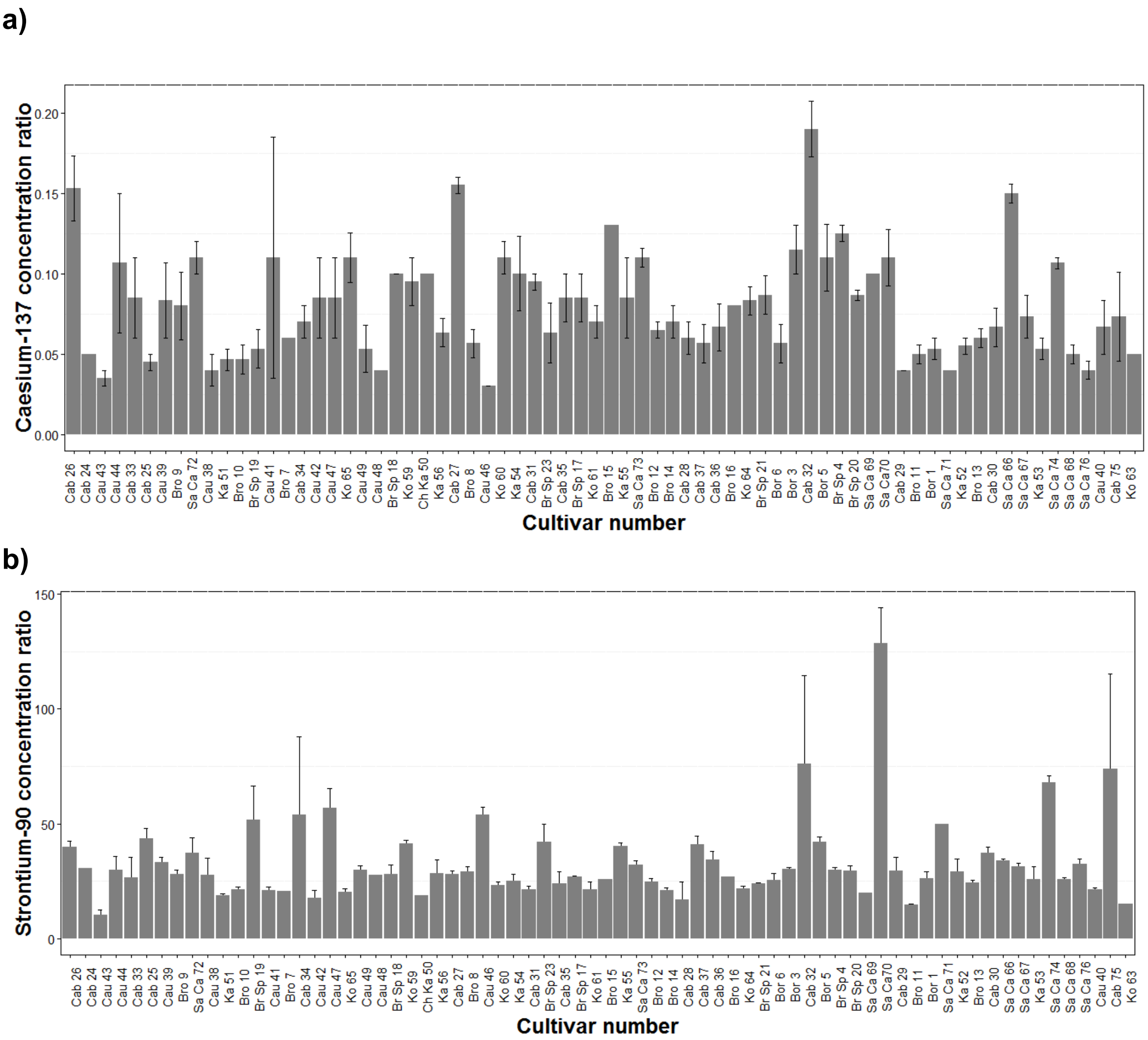


Figure 5 (a) Caesium-137 concentration ratios and **(b)** strontium-90 concentration ratios for 70 *B. oleracea* cultivars grown in Experiment 4. Cultivars studied in both Experiments 3 and 4 are ordered by their ^{137}Cs concentration ratio in Experiment 3. Cultivars studied only in Experiment 4 are added to the far right of the cultivars studied in both experiments. Data are means (*n*=1-6) +/- standard error of the mean

4. Discussion

4.1 Comparisons with previous studies

The inter-cultivar variation in ^{137}Cs concentration ratios found in Experiments 2 (2.7-fold; Fig. 3) and 4 (6.3-fold; Fig 5a) were higher, but in the same order of magnitude as those found in the paper of Bibak et al. (1999) reporting variation in concentrations of stable Cs in *B. oleracea*, and as the mean inter-cultivar variation in Cs (both stable and radioactive) uptake in 23 plant species as found in Penrose et al. (2015) (2.0-fold). The inter-cultivar variation in ^{137}Cs concentration ratios in Experiment 3 was substantially greater (35-fold; Fig. 4a) than in

Penrose et al. (2015) and Bibak et al. (1999). The variation in ^{90}Sr concentration ratios in Experiments 3 (23-fold; Fig. 4b) and 4 (12-fold; Fig. 5b) were both an order of magnitude greater than the 4.2-fold variation observed by Bibak et al. (1999), and the average inter-cultivar variation in Sr uptake by 20 plant species (2.0-fold) reported in Penrose et al. (2015). However, once again fewer cultivars were studied by Bibak et al. (1999, *n*=2) and in the studies reported by Penrose et al. (2015, *n*≈7) than in Experiments 3 or 4 (*n*=71 and 70, respectively). The larger range in concentration ratios found in our experiments may be due to a larger number of cultivars used in Experiments 2 (*n*=27), 3 (*n*=71) and 4 (*n*=70) in comparison to the number used in Bibak et al. (1999; *n*=2) and the average number of cultivars used in the experiments reviewed by Penrose et al. (2015; *n*≈7); variation will be likely to increase with sample size. As there is extensive morphological variation in *B. oleracea*, it is possible that Cs and Sr concentration ratios vary more in this species than others. However, multi-variety field experiments would need to be conducted for many species and in multiple locations to determine whether *B. oleracea* has inherently more or less variation in Cs and Sr concentration ratios than other species.

4.2 Soil sampling

As the soil samples were only taken from the top 10 cm instead of the top 20 cm as recommended by the IAEA (IAEA, 2010), care should be taken when using these values for human food chain assessment. However, as the soil had been rotavated prior to sowing, the authors believe that the soil was well mixed and therefore soil activity concentrations were representative of the top soil as a whole.

4.3 Consistency between experiments

To test statistically whether cultivars consistently accumulated more or less than the other cultivars over multiple experiments, cultivars grown in Experiments 2, 3 and 4 were ranked for their mean radiocaesium concentration ratio in each of the three experiments (Table 3). These ranks where then added together to create a total rank for each cultivar.

Table 3 Cultivars grown in Experiments 2, 3 and 4 and their rankings for radiocaesium concentration ratio. The lowest ranking (1) refers to the cultivar with the lowest concentration ratio, the highest ranking (27) refers to the cultivar with the highest concentration ratio

Cultivar number	Morphotype	Experiment 2 ^{134}Cs concentration ratio rank	Experiment 3 ^{137}Cs concentration ratio rank	Experiment 4 ^{137}Cs concentration ratio rank	Total rank
Bor 4	Borecole	5	19	24	48
Bro 10	Broccoli	25	5	3	33
Bro 11	Broccoli	27	23	4.5	54.5
Bro 12	Broccoli	23	14	12	49
Bro 13	Broccoli	22	26	9.5	57.5
Bro 15	Broccoli	18	13	25	56
BrSp 17	Brussels sprout	1	12	14	27
BrSp 18	Brussels sprout	17	7	19	43
BrSp 20	Brussels sprout	14	21	15.5	50.5
BrSp 21	Brussels sprout	24	18	15.5	57.5
BrSp 23	Brussels sprout	9	10.5	11	30.5
Cab 24	Cabbage	12	2	4.5	18.5*
Cab 26	Cabbage	13	1	26	40
Cab 28	Cabbage	10	15	9.5	34.5
Cab 31	Cabbage	16	10.5	17	43.5
Cab 32	Cabbage	19	20	27	66
Cab 36	Cabbage	3	17	13	33
Cab 37	Cabbage	11	16	8	35
Cau 41	Cauliflower	7	6	22.5	35.5
Cau 43	Cauliflower	20	3.5	1	24.5
Cau 44	Cauliflower	15	3.5	21	39.5
ChKa 50	Chinese kale	4	8	19	31
Ka 52	Kale	6	25	7	38

Ka 53	Kale	2	27	6	35
Ko 60	Kohlrabi	21	9	22.5	52.5
SaCa 69	Savoy cabbage	26	22	19	67#
SaCa 71	Savoy cabbage	8	24	2	34

**Denotes cultivars that consistently accumulated less*
 # Denotes cultivars that consistently accumulated more

To identify cultivars with consistently lower or higher concentration ratios, three random numbers between 1 and 27 (the minimum and maximum rank) were added together to create a simulated 'total rank'. This process was iterated 1000 times, and the 5th and 95th percentile calculated. Any cultivar with a total rank below the 5th percentile (i.e. below 20 for this simulation) was considered consistently low-ranking, and any cultivar with a total rank above the 95th percentile (i.e. 66 for this simulation) was deemed consistently high-ranking. Cab 24 (Total rank=18.5) had a consistently lower radiocaesium concentration ratio, and SaCa 69 (Total rank=67) was identified as a cultivar with a consistently higher radiocaesium concentration ratio.

The 66 cultivars used in both Experiments 3 and 4 were ranked in terms of their ^{137}Cs and ^{90}Sr concentration ratios, to test consistency using the same method as for the comparison of Experiments 2, 3 and 4 (Table 4). This time, two random numbers between one and 66 were added together to create a simulated 'total rank'.

Five cultivars, Cau 43 (Total ^{137}Cs rank=6), Cab 24 (Total ^{137}Cs rank=13), Cab 25 (Total ^{137}Cs rank=13), Cau 38 (Total ^{137}Cs rank=14.5) and Ka 51 (Total ^{137}Cs rank=20) had consistently lower ^{137}Cs concentration ratios. Two cultivars, Cab 32 (Total ^{137}Cs rank=116) and SaCa 66 (Total ^{137}Cs rank=125) had consistently higher ^{137}Cs concentration ratios.

Two cultivars, Ko 65 (Total ^{90}Sr rank=14) and Bro 7 (Total ^{90}Sr rank=21) had consistently lower ^{90}Sr concentration ratios. Three cultivars, SaCa 71, Cau 46 and Cau 47 had consistently higher ^{90}Sr concentration ratios (Total ^{90}Sr rank=118, 126 and 119, respectively).

Bro 10 had consistently lower ^{137}Cs and ^{90}Sr concentration ratios (Total ^{137}Cs rank=20; Total ^{90}Sr rank=21). Cultivar SaCa 74 had consistently higher ^{137}Cs and ^{90}Sr concentration ratios (Total ^{137}Cs rank=116.5; Total ^{90}Sr rank=117).

Table 4 Cultivars grown in Experiments 3 and 4 and their rankings for ^{137}Cs and ^{90}Sr concentration ratios

Cultivar number	Morphotype	Experiment 3 ^{137}Cs concentration ratio rank	Experiment 4 ^{137}Cs concentration ratio rank	Experiment 3 ^{90}Sr concentration ratio rank	Experiment 4 ^{90}Sr concentration ratio rank	Total ^{137}Cs concentration ratio rank	Total ^{90}Sr concentration ratio rank
Bor 6	Borecole	48	19	35	22	67	57
Bor 1	Borecole	57	14.5	5	26	71.5	31
Bor 5	Borecole	51	56	29	57	107	86
Bor 4	Borecole	47	61	51	40	108	91
Bor 3	Borecole	49	60	4	43	109	47
Bro 10	Broccoli	11.5	8.5	7	14	20*	21*
Bro 7	Broccoli	15	22	12	9	37	21*
Bro 9	Broccoli	8	33.5	11	34	41.5	45
Bro 8	Broccoli	27	19	26	36	46	62
Bro 12	Broccoli	39	26	25	20	65	45
Bro 11	Broccoli	56	11	62	2	67	64
Bro 14	Broccoli	40	30	52	11	70	63
Bro 16	Broccoli	44	33.5	33	29	77.5	62
Bro 13	Broccoli	60	22	58	19	82	77
Bro 15	Broccoli	36	62	20	23	98	43
BrSp 19	Brussels sprout	13.5	14.5	17	60	28	77
BrSp 23	Brussels sprout	31	24.5	14	56	55.5	70
BrSp 18	Brussels sprout	22.5	48.5	18	33	71	51
BrSp 17	Brussels sprout	34	39.5	16	28	73.5	44
BrSp 21	Brussels sprout	46	43.5	32	18	89.5	50
BrSp 20	Brussels sprout	52	43.5	21	39	95.5	60
Cab 25	Cabbage	6	7	19	58	13*	77
Cab 24	Cabbage	2	11	30	44	13*	74
Cab 33	Cabbage	4	39.5	44	27	43.5	71
Cab 34	Cabbage	16	30	28	62	46	90
Cab 29	Cabbage	55	4.5	31	38	59.5	69

Cab 37	Cabbage	42	19	23	54	61	77
Cab 28	Cabbage	41	22	45	3	63	48
Cab 26	Cabbage	1	64	36	52	65	88
Cab 36	Cabbage	43	27.5	46	49	70.5	95
Cab 35	Cabbage	33	39.5	40	17	72.5	57
Cab 31	Cabbage	31	45.5	41	13	76.5	54
Cab 30	Cabbage	61	27.5	50	50	88.5	100
Cab 27	Cabbage	26	65	10	32	91	42
Cab 32	Cabbage	50	66	43	65	116#	108
Cau 43	Cauliflower	4	2	59	1	6*	60
Cau 38	Cauliflower	10	4.5	64	30	14.5*	94
Cau 48	Cauliflower	21	4.5	49	31	25.5	80
Cau 46	Cauliflower	28	1	65	61	29	126#
Cau 49	Cauliflower	20	14.5	8	41	34.5	49
Cau 39	Cauliflower	8	35.5	60	47	43.5	107
Cau 44	Cauliflower	4	51.5	61	42	55.5	103
Cau 42	Cauliflower	17	39.5	57	4	56.5	61
Cau 47	Cauliflower	18	39.5	56	63	57.5	119#
Cau 41	Cauliflower	13.5	56	54	10	69.5	64
ChKa 50	Chinese kale	24	48.5	47	5	72.5	52
Ka 51	Kale	11.5	8.5	24	6	20*	30
Ka 56	Kale	25	24.5	2	35	49.5	37
Ka 52	Kale	59	17	55	37	76	92
Ka 55	Kale	37	39.5	27	53	76.5	80
Ka 53	Kale	64	14.5	66	25	78.5	91
Ka 54	Kale	31	48.5	42	21	79.5	63
Ko 61	Kohlrabi	35	30	15	12	65	27
Ko 59	Kohlrabi	22.5	45.5	22	55	68	77
Ko 65	Kohlrabi	19	56	6	8	75	14*
Ko 64	Kohlrabi	45	35.5	9	15	80.5	24
Ko 60	Kohlrabi	29	56	37	16	85	53

SaCa 71	Savoy cabbage	58	4.5	63	59	62.5	122#
SaCa 72	Savoy cabbage	8	56	1	51	64	52
SaCa 68	Savoy cabbage	66	11	38	24	77	62
SaCa 73	Savoy cabbage	38	56	13	46	94	59
SaCa 67	Savoy cabbage	63	32	34	45	95	79
SaCa 69	Savoy cabbage	53.5	48.5	48	7	102	55
SaCa 70	Savoy cabbage	53.5	56	3	66	109.5	69
SaCa 74	Savoy cabbage	65	51.5	53	64	116.5#	117#
SaCa 66	Savoy cabbage	62	63	39	48	125#	87

**Denotes cultivars that consistently accumulated less*
 # Denotes cultivars that consistently accumulated more

In a recent meta-analysis comprising 27 plant species, cultivars that had consistently the lowest Cs or Sr concentration ratios over multiple sites were found in five out of eight sets of experiments (Penrose et al., 2015). In three out of the eight sets of experiments, no cultivar was found to have consistently the lowest concentration ratio. However, there were far fewer (range=2-28) cultivars included in the experiments reported by Penrose et al. (2015), and thus consistency in concentration ratios in these studies was measured by testing whether the cultivar with the lowest concentration ratio at one site had the lowest concentration ratio at all sites. As the study reported here includes more cultivars (27-66), this method of testing for consistency in concentration ratios was not appropriate, thus the 5^{th} and 95^{th} percentile were used. Our research supports the hypothesis that it is possible to identify cultivars that have consistently lower radiocaesium or radiostrontium concentration ratios at multiple sites.

4.4 Brassica oleracea *as a contributor to human radioactive dose*

This study has identified *B. oleracea* cultivars that have consistently lower radiocaesium and/or radiostrontium concentration ratios, which suggests that cultivar selection or substitution might be an effective remediation strategy in radiologically contaminated areas. The evidence for genetic variation in Cs accumulation in *B. oleracea* shown in this study could have an immediate beneficial effect for populations who inhabit and consume crops that have been grown on radiocaesium contaminated land. Utilising these cultivars with lower concentration ratios could be a cost effective way to reduce both individual and collective doses of radiocaesium and radiostrontium. Additionally, these findings could provide an example to breeders of other crop species showing that substantial variation in uptake of radiocaesium and radiostrontium can occur between plant cultivars. However, it may be that consumers have a preference for one varietas in favour of another, and therefore we recommend that further studies include more cultivars from each varietas to investigate further the variation within varietas. Additionally, due to relatively low consumption of leafy vegetables in the typical diet, *B. oleracea* is unlikely to be a main contributor to human radioactive dose. For example, a study investigating the contribution of foodstuffs to daily ^{137}Cs intake in two settlements in

Ukraine found that vegetables only contributed to 3.6-4.5% of ^{137}Cs intake from foodstuffs, whereas bread, potatoes and milk contributed 6.8-11%, 9.5-19% and 13-50%, respectively (Beresford et al., 2001). It is therefore recommended that future research regarding cultivar substitution should focus on crop species that are likely to be major contributors to human radioactive dose, such as grains, potato and animal fodders.

5. Conclusion

Up to 35-fold variation in radiocaesium concentration ratios and 23-fold variation in radiostrontium concentration ratios was found between 71 cultivars of *B. oleracea* in individual experiments (Figs 3, 4, 5). When results of three experiments (one performed in a controlled environment and two field experiments performed in the Chernobyl Exclusion Zone) were compared, only one (a cabbage) out of the 27 cultivars studied was found to have lower radiocaesium concentration ratios in all three experiments. When results of the two field experiments were compared, five (two cauliflower, two cabbage, one kale) out of the 66 cultivars common to both experiments were found to be consistently lower ^{137}Cs accumulators, and two (one kohlrabi, one broccoli) were found to be consistently lower ^{90}Sr accumulators. One cultivar (a broccoli) was found to consistently accumulate less ^{137}Cs and ^{90}Sr than the other cultivars. Cultivars that consistently accumulate less radiocaesium and/or radiostrontium indicate that cultivar selection or substitution might be an effective remediation strategy in radiologically contaminated areas. However, as *B. oleracea* is a relatively minor crop, it is recommended that future research focuses on plant species such as grains, potatoes and animal fodders, that have greater contributors to human radioactive dose either directly or indirectly through their importance in the diet of farm animals.

6. Acknowledgements

BP was supported by the UK Natural Environment Research Council (Grant number NE/K500951/1). KAJ was supported by a UK Biotechnology and Biological Sciences

Research Council (BBSRC) Plant and Microbial Sciences Committee Studentship (01/B1/P/07523). PJW, MRB, NAB and AA were support by Royal Society Project No. 15350 “Exploiting plant genetic variation to minimise radiocaesium in the food chain”.

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Experiment 2 (Growth chamber)					
Cultivar	Morphotype	Soil_Cs-134 _KBq kg-1_(d. wt)	Plant_Cs-134 _KBq kg-1_(d. wt)	Cs-134 _concentration_ ratio	Plant_dry _weight_ g
Bor 4	Borecole	17.4	3.78	0.217	0.1598
Bor 4	Borecole	18.1	5.55	0.307	0.13455
Bor 4	Borecole	21	6.55	0.312	0.06468
Bro 10	Broccoli	16.6	10.62	0.640	0.04236
Bro 10	Broccoli	21.9	10.82	0.494	0.12899
Bro 10	Broccoli	19.6	8.6	0.439	0.11304
Bro 11	Broccoli	18	11.63	0.646	0.13912
Bro 11	Broccoli	16.3	11.5	0.706	0.05066
Bro 11	Broccoli	19.2	11.4	0.594	0.03942
Bro 12	Broccoli	13.8	4.97	0.360	0.18576
Bro 12	Broccoli	20.7	13.29	0.642	0.04739
Bro 12	Broccoli	15.8	7.04	0.446	0.05796
Bro 13	Broccoli	18	4.82	0.268	0.02391
Bro 13	Broccoli	18.5	9.77	0.528	0.03805
Bro 13	Broccoli	26.8	17.43	0.650	0.0426
Bro 15	Broccoli	14.2	5.94	0.418	0.22784
Bro 15	Broccoli	29.1	11.94	0.410	0.09726
Bro 15	Broccoli	19.8	8.04	0.406	0.07977
Br Sp 17	Brussels sprout	17.3	4.24	0.245	0.0686
Br Sp 17	Brussels sprout	14.7	3.76	0.256	0.06945
Br Sp 17	Brussels sprout	18.4	4.1	0.223	0.0336
Br Sp 18	Brussels sprout	21.9	7.75	0.354	0.06558
Br Sp 18	Brussels sprout	22	13.05	0.593	0.03223
Br Sp 18	Brussels sprout	21.8	6.16	0.283	0.07679
Br Sp 20	Brussels sprout	15.5	5.4	0.348	0.01436
Br Sp 20	Brussels sprout	15.6	3.88	0.249	0.06565
Br Sp 20	Brussels sprout	21.8	9.52	0.437	0.02536
Br Sp 21	Brussels sprout	18.9	5.75	0.304	0.10245
Br Sp 21	Brussels sprout	17.3	4.69	0.271	0.05213
Br Sp 21	Brussels sprout	17.3	16.56	0.957	0.0194
Br Sp 23	Brussels sprout	18	6.95	0.386	0.14733
Br Sp 23	Brussels sprout	16	3.28	0.205	0.03305
Br Sp 23	Brussels sprout	16.8	5.38	0.320	0.03948
Cab 24	Cabbage	16.2	3.32	0.205	0.1551
Cab 24	Cabbage	24.3	9.43	0.388	0.06362
Cab 24	Cabbage	23.9	10.04	0.420	0.03845
Cab 26	Cabbage	15.4	6.03	0.392	0.09269
Cab 26	Cabbage	21.3	3.79	0.178	0.20632
Cab 26	Cabbage	21.2	9.53	0.450	0.03327
Cab 28	Cabbage	21	4.87	0.232	0.0481
Cab 28	Cabbage	17.6	6.4	0.364	0.11723
Cab 28	Cabbage	19.8	6.55	0.331	0.06701
Cab 31	Cabbage	18.6	6.66	0.358	0.08134
Cab 31	Cabbage	15.9	4.98	0.313	0.05708
Cab 31	Cabbage	20.3	9.87	0.486	0.02973
Cab 32	Cabbage	17.1	7.61	0.445	0.08641

Cab 32	Cabbage	16.5	6.94	0.421	0.06974
Cab 32	Cabbage	18.4	7.02	0.382	0.07998
Cab 36	Cabbage	24.9	5.89	0.237	0.07148
Cab 36	Cabbage	18.9	3.74	0.198	0.06158
Cab 36	Cabbage	17.9	6.51	0.364	0.05143
Cab 37	Cabbage	21.1	7.5	0.355	0.07418
Cab 37	Cabbage	25.3	6.8	0.269	0.08781
Cab 37	Cabbage	21.4	7.46	0.349	0.0819
Cau 41	Caulifower	16.9	4.51	0.267	0.0927
Cau 41	Caulifower	13.7	3.23	0.236	0.0719
Cau 41	Caulifower	19.7	7.69	0.390	0.02141
Cau 43	Caulifower	21.2	7.01	0.331	0.05217
Cau 43	Caulifower	20	6.74	0.337	0.03522
Cau 43	Caulifower	18.4	11.75	0.639	0.01905
Cau 44	Caulifower	22.2	9.32	0.420	0.06788
Cau 44	Caulifower	16.8	6.07	0.361	0.02963
Cau 44	Caulifower	19.7	6.97	0.354	0.02849
Ch Ka 50	Chinese kale	17	4.55	0.268	0.17732
Ch Ka 50	Chinese kale	16.1	3.96	0.246	0.06195
Ch Ka 50	Chinese kale	19.4	6.1	0.314	0.05156
Ka 52	Kale	20.4	5.02	0.246	0.0131
Ka 52	Kale	23.2	7.27	0.313	0.11934
Ka 52	Kale	20.8	6.75	0.325	0.06394
Ka 53	Kale	16.4	4.83	0.295	0.0963
Ka 53	Kale	31.8	5.44	0.171	0.13957
Ka 53	Kale	19.1	6.11	0.320	0.06687
Ko 60	Kohlrabi	19.5	6.94	0.356	0.08745
Ko 60	Kohlrabi	23.2	13.07	0.563	0.07883
Ko 60	Kohlrabi	16.9	8.67	0.513	0.12502
Sa Ca 69	Savoy cabbage	19	13.01	0.685	0.11852
Sa Ca 69	Savoy cabbage	19.1	7.63	0.399	0.06498
Sa Ca 69	Savoy cabbage	18.1	9.29	0.513	0.08281
Sa Ca 71	Savoy cabbage	19.4	4.67	0.241	0.0902
Sa Ca 71	Savoy cabbage	22.4	6.27	0.280	0.08382
Sa Ca 71	Savoy cabbage	14.9	5.58	0.374	0.08138

Experiment 3 (Ukraine, 2003)

Cultivar	Morphotype	Soil_Cs-137 _KBq kg-1 (d. wt)	Soil_Sr-90 _KBq kg-1 (d. wt)	Plant_Cs-137 _KBq kg-1 (d. wt)
Bor 1	Borecole	0.331	0.142	0.128
Bor 1	Borecole	1.345	0.473	0.432
Bor 1	Borecole	1.887	0.732	0.642
Bor 2	Borecole	0.843	0.342	0.047
Bor 3	Borecole	0.155	0.047	0.036
Bor 3	Borecole	2.752	1.22	0.813
Bor 4	Borecole	0.163	0.079	0.053
Bor 4	Borecole	0.933	0.45	0.196
Bor 4	Borecole	2.051	0.788	0.487
Bor 5	Borecole	3.565	1.216	0.972
Bor 5	Borecole	1.985	0.915	0.478
Bor 5	Borecole	0.262	0.075	0.083
Bor 6	Borecole	0.189	0.133	0.087
Bor 6	Borecole	0.357	0.248	0.079
Bor 6	Borecole	2.865	1.391	0.329
Bro 7	Broccoli	3.72	1.653	0.173
Bro 7	Broccoli	0.62	0.299	0.047
Bro 8	Broccoli	5.674	3.312	0.469
Bro 8	Broccoli	0.208	0.046	0.029
Bro 9	Broccoli	0.569	0.283	0.028
Bro 9	Broccoli	0.887	0.952	0.048
Bro 10	Broccoli	1.792	0.699	0.084
Bro 10	Broccoli	2.106	0.861	0.116
Bro 11	Broccoli	1.434	0.496	0.5
Bro 11	Broccoli	1.471	0.711	0.487
Bro 12	Broccoli	0.165	0.025	0.044
Bro 12	Broccoli	2.207	0.854	0.264
Bro 13	Broccoli	0.199	0.05	0.092
Bro 13	Broccoli	1.379	0.514	0.618
Bro 14	Broccoli	0.248	0.112	0.063
Bro 14	Broccoli	3.812	1.294	0.572
Bro 15	Broccoli	1.098	0.542	0.203
Bro 15	Broccoli	1.753	0.744	0.311
Bro 15	Broccoli	3.743	1.851	0.538
Br 16	Broccoli	1.349	0.534	0.382
Br 16	Broccoli	2.692	1.232	0.515
Br 16	Broccoli	0.152	0.01	0.038
Br Sp 17	Brussels sprout	3.738	1.274	0.638
Br Sp 17	Brussels sprout	5.475	3.157	0.594
Br Sp 18	Brussels sprout	0.986	0.423	0.106
Br Sp 18	Brussels sprout	1.811	1.276	0.207
Br Sp 18	Brussels sprout	2.582	0.92	0.218
Br Sp 19	Brussels sprout	0.479	0.206	0.029
Br Sp 19	Brussels sprout	2.958	1.481	0.164
Br Sp 20	Brussels sprout	0.226	0.022	0.069
Br Sp 20	Brussels sprout	2.777	0.727	0.821

Br Sp 20	Brussels sprout	4.292	2.36	1.063
Br Sp 21	Brussels sprout	1.853	0.879	0.517
Br Sp 21	Brussels sprout	2.989	1.049	0.73
Br Sp 21	Brussels sprout	2.714	1.163	0.683
Br Sp 22	Brussels sprout	1.438	0.93	0.438
Br Sp 22	Brussels sprout	2.745	1.037	0.728
Br Sp 23	Brussels sprout	0.43	0.191	0.063
Br Sp 23	Brussels sprout	4.944	2.794	0.727
Br Sp 23	Brussels sprout	3.522	2.101	0.329
Cab 24	Cabbage	0.656	0.179	0.032
Cab 24	Cabbage	1.427	0.536	0.049
Cab 24	Cabbage	2.501	1.016	0.063
Cab 25	Cabbage	0.152	0.019	0.006
Cab 25	Cabbage	1.73	0.799	0.083
Cab 25	Cabbage	2.566	0.991	0.106
Cab 26	Cabbage	0.51	0.119	0.016
Cab 26	Cabbage	2.13	0.784	0.074
Cab 26	Cabbage	2.053	0.782	0.062
Cab 27	Cabbage	0.429	0.204	0.053
Cab 27	Cabbage	1.94	0.754	0.193
Cab 27	Cabbage	3.256	1.568	0.32
Cab 28	Cabbage	0.4	0.202	0.072
Cab 28	Cabbage	1.795	0.687	0.407
Cab 29	Cabbage	0.831	0.487	0.377
Cab 29	Cabbage	2.669	1.134	0.473
Cab 29	Cabbage	0.255	0.09	0.084
Cab 30	Cabbage	1.922	0.673	0.671
Cab 30	Cabbage	0.707	0.272	0.488
Cab 30	Cabbage	2.086	0.821	0.729
Cab 31	Cabbage	0.331	0.241	0.046
Cab 31	Cabbage	0.562	0.18	0.084
Cab 31	Cabbage	2.657	1.096	0.275
Cab 32	Cabbage	1.976	0.832	0.591
Cab 32	Cabbage	0.33	0.113	0.078
Cab 33	Cabbage	2.31	0.919	0.094
Cab 34	Cabbage	1.6	0.783	0.093
Cab 34	Cabbage	2.703	1.117	0.263
Cab 34	Cabbage	0.17	0.028	0.011
Cab 35	Cabbage	1.392	0.483	0.201
Cab 35	Cabbage	3.069	1.273	0.404
Cab 36	Cabbage	1.553	0.551	0.373
Cab 36	Cabbage	2.979	1.058	0.632
Cab 36	Cabbage	3.178	1.337	0.705
Cab 37	Cabbage	3.087	1.07	0.638
Cab 37	Cabbage	0.354	0.128	0.072
Cab 37	Cabbage	0.916	0.627	0.216
Cau 38	Cauliflower	0.349	0.217	0.018
Cau 38	Cauliflower	2.919	1.237	0.174
Cau 38	Cauliflower	0.934	0.343	0.046
Cau 39	Cauliflower	1.06	0.686	0.057
Cau 39	Cauliflower	2.378	1.1	0.107

Cau 41	Cauliflower	2.809	1.163	0.175
Cau 42	Cauliflower	2.457	1.025	0.209
Cau 42	Cauliflower	0.614	0.217	0.044
Cau 43	Cauliflower	1.768	0.672	0.072
Cau 44	Cauliflower	0.56	0.183	0.021
Cau 46	Cauliflower	0.149	0.05	0.016
Cau 46	Cauliflower	1.672	0.992	0.209
Ca 47	Cauliflower	0.496	0.249	0.039
Cau 48	Cauliflower	0.197	0.012	0.019
Cau 48	Cauliflower	1.094	0.737	0.105
Cau 49	Cauliflower	0.156	0.03	0.014
Ch Ka 50	Chinese kale	2.243	0.911	0.278
Ch Ka 50	Chinese kale	1.711	0.685	0.173
Ch Ka 50	Chinese kale	0.173	0.006	0.016
Ka 51	Kale	2.209	1.025	0.103
Ka 51	Kale	0.807	0.243	0.05
Ka 52	Kale	0.588	0.309	0.184
Ka 52	Kale	2.243	0.878	1.085
Ka 53	Kale	0.15	0.024	0.098
Ka 53	Kale	1.629	0.647	0.835
Ka 53	Kale	3.021	0.99	1.593
Ka 54	Kale	0.102	0.068	0.014
Ka 54	Kale	1.313	0.471	0.163
Ka 55	Kale	3.462	1.462	0.373
Ka 55	Kale	0.102	0.021	0.026
Ka 55	Kale	0.73	0.373	0.108
Ka 56	Kale	3.082	1.29	0.342
Ka 56	Kale	0.583	0.194	0.059
Ko 57	Kohlrabi	0.548	0.172	0.069
Ko 57	Kohlrabi	0.167	0.11	0.02
Ko 58	Kohlrabi	0.426	0.089	0.041
Ko 58	Kohlrabi	1.639	1.263	0.149
Ko 58	Kohlrabi	4.924	2.902	0.385
Ko 59	Kohlrabi	0.323	0.223	0.03
Ko 59	Kohlrabi	2.86	1.246	0.285
Ko 59	Kohlrabi	0.906	0.325	0.097
Ko 60	Kohlrabi	1.752	0.708	0.174
Ko 60	Kohlrabi	2.41	0.861	0.292
Ko 60	Kohlrabi	2.796	1.691	0.381
Ko 61	Kohlrabi	2.764	1.329	0.416
Ko 61	Kohlrabi	2.086	1.294	0.328
Ko 62	Kohlrabi	0.101	0.007	0.013
Ko 62	Kohlrabi	3.412	1.177	0.373
Ko 64	Kohlrabi	2.487	1.087	0.604
Ko 64	Kohlrabi	1.372	1.006	0.369
Ko 65	Kohlrabi	1.019	0.376	0.094
Ko 65	Kohlrabi	3.83	1.803	0.298
Sa Ca 66	Savoy cabbage	0.105	0.014	0.054
Sa Ca 66	Savoy cabbage	1.528	0.579	0.628
Sa Ca 67	Savoy cabbage	3.615	1.912	1.429
Sa Ca 67	Savoy cabbage	1.438	0.619	0.633

Sa Ca 67	Savoy cabbage	1.179	0.536	0.792
Sa Ca 67	Savoy cabbage	2.594	1.083	1.398
Sa Ca 68	Savoy cabbage	1.209	0.599	0.729
Sa Ca 68	Savoy cabbage	2.152	0.827	1.2
Sa Ca 68	Savoy cabbage	0.048	0.02	0.094
Sa Ca 69	Savoy cabbage	0.056	0.029	0.028
Sa Ca 69	Savoy cabbage	2.557	0.916	0.629
Sa Ca 69	Savoy cabbage	2.691	0.96	0.528
Sa Ca 70	Savoy cabbage	0.501	0.207	0.166
Sa Ca 70	Savoy cabbage	2.739	1.098	0.828
Sa Ca 70	Savoy cabbage	0.966	0.835	0.303
Sa Ca 71	Savoy cabbage	1.666	0.652	0.542
Sa Ca 71	Savoy cabbage	2.506	0.916	0.943
Sa Ca 72	Savoy cabbage	5.469	3.213	0.287
Sa Ca 72	Savoy cabbage	1.437	0.508	0.068
Sa Ca 73	Savoy cabbage	1.303	0.537	0.276
Sa Ca 73	Savoy cabbage	2.245	1.009	0.385
Sa Ca 73	Savoy cabbage	1.806	0.706	0.269
Sa Ca 74	Savoy cabbage	0.359	0.193	0.275
Sa Ca 74	Savoy cabbage	2.587	1.025	0.843
Sa Ca 74	Savoy cabbage	0.445	0.214	0.319

Plant_Sr-90 _KBq kg-1 (d. wt)	Cs-137_ concentration_ ratio	Sr-90_ concentration_r atio	Plant_dry _weight_ g
1.532	0.39	10.79	10.76
3.531	0.32	7.46	2.07
6.346	0.34	8.66	16.31
4.382	0.06	12.8	6.94
0.452	0.23	9.56	12.67
9.543	0.3	7.82	4.12
2.065	0.33	26.22	1.72
10.373	0.21	23.04	14.99
18.393	0.24	23.34	10.42
14.824	0.27	12.19	5.85
12.934	0.24	14.13	4.46
1.407	0.32	18.72	6.66
2.763	0.46	20.82	3.31
4.296	0.22	17.31	2.63
14.839	0.11	10.67	1.45
14.826	0.05	8.97	6.38
3.725	0.08	12.44	5.22
19.956	0.08	6.03	22.89
0.935	0.14	20.16	3.13
3.265	0.05	11.54	4.86
9.378	0.05	9.85	5.61
6.817	0.05	9.75	8.14
7.482	0.06	8.69	5.4
18.65	0.35	37.59	29
23.943	0.33	33.66	22.21
0.393	0.27	15.88	14.5
8.736	0.12	10.23	15.22
1.65	0.46	33.18	13.28
17.829	0.45	34.66	4.89
3.378	0.25	30.18	1.07
23.618	0.15	18.26	6.37
7.284	0.18	13.44	4.51
8.935	0.18	12	2.32
18.037	0.14	9.74	3.45
6.294	0.28	11.78	0.95
14.284	0.19	11.59	7.66
0.248	0.25	24.45	4.46
17.328	0.17	13.6	11.67
27.896	0.11	8.84	22.61
4.721	0.11	11.16	15.04
13.643	0.11	10.69	4.3
11.299	0.08	12.28	22.47
2.398	0.06	11.62	3.32
16.415	0.06	11.08	17.63
0.345	0.31	15.55	19.99
8.231	0.3	11.32	2.79

19.934	0.25	8.45	1
13.729	0.28	15.63	9.1
17.265	0.24	16.46	2.61
17.903	0.25	15.4	21.85
8.284	0.3	8.91	6.43
9.073	0.27	8.75	7.12
2.04	0.15	10.69	9.99
26.43	0.15	9.46	4.89
26.538	0.09	12.63	6.61
2.836	0.05	15.83	5.04
8.335	0.03	15.56	8.58
14.042	0.03	13.83	7.74
0.284	0.04	14.94	9.81
7.922	0.05	9.91	16.1
9.36	0.04	9.45	1.17
1.833	0.03	15.36	2.36
12.943	0.03	16.51	23.32
13.36	0.03	17.07	18.33
2.15	0.12	10.55	19.43
8.855	0.1	11.74	2.72
13.48	0.1	8.6	21.21
4.173	0.18	20.69	2.47
14.593	0.23	21.25	12.18
4.927	0.45	10.11	10.46
8.933	0.18	7.87	14.23
2.489	0.33	27.52	1.09
17.928	0.35	26.63	15.44
7.094	0.69	26.04	3.64
16.328	0.35	19.89	10.43
4.974	0.14	20.62	3.19
3.963	0.15	22.04	6.96
13.924	0.1	12.71	6.08
15.052	0.3	18.1	1.49
2.592	0.24	22.84	8.12
18.933	0.04	20.6	6.5
12.397	0.06	15.83	1.89
14.387	0.1	12.89	13.06
0.403	0.06	14.16	3.3
10.039	0.14	20.8	10.16
18.307	0.13	14.38	2.51
14.947	0.24	27.12	4.4
21.046	0.21	19.9	5.2
24.803	0.22	18.55	8.18
12.639	0.21	11.81	1.93
2.017	0.2	15.77	7.51
5.724	0.24	9.13	1.62
10.583	0.05	48.68	2.54
39.464	0.06	31.89	3.83
12.783	0.05	37.3	5.89
24.843	0.05	36.24	4.51
36.829	0.05	33.48	0.97

32.574	0.06	28.02	5.17
28.463	0.08	27.76	1.16
8.474	0.07	39.01	3.75
23.383	0.04	34.78	3.04
6.397	0.04	35.01	1.07
2.265	0.11	45.63	6.23
35.126	0.12	35.43	8.44
7.685	0.08	30.81	4.54
0.385	0.09	30.84	9.35
12.763	0.1	17.32	2.79
0.284	0.09	9.33	6.52
18.744	0.12	20.57	14.54
12.382	0.1	18.08	3.8
0.173	0.09	27.06	2.5
12	0.05	11.71	2.68
3.378	0.06	13.88	11.61
10.383	0.31	33.65	1.71
24.032	0.48	27.36	4.09
1.55	0.66	65.38	3.23
25.933	0.51	40.08	4.36
32.041	0.53	32.38	2.54
1.306	0.14	19.17	5.49
9.604	0.12	20.39	1.88
14.925	0.11	10.21	7.18
0.372	0.25	17.56	3.21
4.383	0.15	11.75	16.18
5.389	0.11	4.18	9.93
0.837	0.1	4.3	1.52
1.642	0.13	9.53	9.96
1.053	0.12	9.59	8.76
0.933	0.1	10.51	3.56
12.032	0.09	9.53	1.22
17.933	0.08	6.18	2.56
2.839	0.09	12.72	1.01
14.403	0.1	11.56	1.04
3.723	0.11	11.44	1.24
14.329	0.1	20.23	11.04
16.21	0.12	18.83	11.77
18.622	0.14	11.01	3.35
14.15	0.15	10.64	2.32
14.93	0.16	11.54	28.98
0.075	0.13	11.42	1.94
12.319	0.11	10.47	12.62
10.048	0.24	9.24	10.71
9.843	0.27	9.78	6.05
3.392	0.09	9.01	1.7
16.932	0.08	9.39	10.03
0.219	0.52	15.86	1.91
11.093	0.41	19.16	8.2
23.733	0.4	12.41	1.01
11.428	0.44	18.46	1.15

9.835	0.67	18.36	4.48
16.288	0.54	15.04	4.68
3.825	0.6	6.38	12.51
8	0.56	9.68	1.07
0.728	1.98	35.58	13.4
0.833	0.49	28.71	1.64
15.739	0.25	17.18	3.81
19.033	0.2	19.83	7.87
1.65	0.33	7.98	15.46
7.285	0.3	6.63	29.47
5.928	0.31	7.1	7.86
26.071	0.33	39.97	28.72
31.934	0.38	34.85	4.12
7.362	0.05	2.29	5.06
0.871	0.05	1.71	3.71
6.628	0.21	12.35	12.28
9.469	0.17	9.38	22.73
7.365	0.15	10.44	8.05
5.933	0.77	30.79	10.29
18.735	0.33	18.27	2.66
5.722	0.72	26.69	14.85

		Experiment 4 (Ukraine, 2004)			
Cultivar	Morphotype	Soil_Cs-137 _KBq kg-1 (d. wt)	Soil_Sr-90 _KBq kg-1 (d. wt)	Plant_Cs-137 _KBq kg-1 (d. wt)	Plant_Sr-90 _KBq kg-1 (d. wt)
Bor 1	Borecole	2.7	1.4	0.15	29.6
Bor 1	Borecole	3	1.6	0.18	50.9
Bor 1	Borecole	3.5	1.5	0.15	37.6
Bor 3	Borecole	2.7	1.1	0.27	34
Bor 3	Borecole	3	2	0.375	59.7
Bor 5	Borecole	2.8	0.96	0.41	41.5
Bor 5	Borecole	2.7	1	0.27	44.9
Bor 5	Borecole	3.6	1.1	0.27	42.1
Bor 6	Borecole	2.8	0.7	0.21	21.7
Bor 6	Borecole	3	2	0.12	46.9
Bor 6	Borecole	3.4	1.4	0.17	31.1
Bro 7	Broccoli	2.6	1.4	0.15	28.9
Bro 8	Broccoli	3	1.6	0.13	39.8
Bro 8	Broccoli	3.2	0.77	0.22	22.6
Bro 9	Broccoli	2.6	0.96	0.23	23.6
Bro 9	Broccoli	2.7	0.56	0.29	17.3
Bro 9	Broccoli	3.5	1	0.13	28.9
Bro 10	Broccoli	2.7	1.3	0.088	28.3
Bro 10	Broccoli	2.8	1.5	0.14	34.3
Bro 10	Broccoli	3.8	1.4	0.23	26.9
Bro 11	Broccoli	2.6	1.4	0.14	22
Bro 11	Broccoli	2.8	1.8	0.18	24.4
Bro 11	Broccoli	3.2	1.3	0.14	18.9
Bro 12	Broccoli	3	1.3	0.17	34
Bro 12	Broccoli	3.2	1.3	0.23	29.8
Bro 13	Broccoli	3	1.3	0.16	32.1
Bro 13	Broccoli	2.9	1.2	0.21	31.5
Bro 13	Broccoli	3.2	1.3	0.18	28.8
Bro 14	Broccoli	2.6	0.96	0.21	21.3
Bro 14	Broccoli	3	2	0.15	44.2
Bro 14	Broccoli	2.9	1.4	0.22	26
Bro 15	Broccoli	2.8	1	0.36	25.7
Br 16	Broccoli	2.6	0.96	0.21	26
Br Sp 17	Brussels sprout	2.6	1.4	0.18	38.1
Br Sp 17	Brussels sprout	3.5	1.5	0.34	39.6
Br Sp 18	Brussels sprout	2.6	0.96	0.26	30.8
Br Sp 18	Brussels sprout	4.1	2.4	0.39	57.7
Br Sp 19	Brussels sprout	2.7	1.1	0.15	89.5
Br Sp 19	Brussels sprout	2.8	1.2	0.2	48.9
Br Sp 19	Brussels sprout	2.9	1.5	0.078	48.9
Br Sp 20	Brussels sprout	2.7	0.92	0.24	27
Br Sp 20	Brussels sprout	3	1.3	0.27	43.6
Br Sp 20	Brussels sprout	2.9	1.5	0.22	38.5
Br Sp 21	Brussels sprout	2.7	1.2	0.3	29
Br Sp 21	Brussels sprout	3	1.3	0.22	31.4
Br Sp 21	Brussels sprout	2.9	1.4	0.24	32.6

Br Sp 22	Brussels sprout	2.7	1.3	0.33	37
Br Sp 22	Brussels sprout	3.2	1.3	0.4	40.3
Br Sp 23	Brussels sprout	2.8	0.7	0.15	40.5
Br Sp 23	Brussels sprout	2.8	1.5	0.27	49.1
Br Sp 23	Brussels sprout	3.5	1	0.14	35.4
Cab 24	Cabbage	2.6	1.4	0.13	42.9
Cab 25	Cabbage	3.1	1.3	0.14	51.3
Cab 25	Cabbage	4.7	1	0.2	48
Cab 26	Cabbage	2.6	0.96	0.38	38.6
Cab 26	Cabbage	2.9	1.2	0.36	52.8
Cab 26	Cabbage	2.9	1.4	0.54	49.9
Cab 27	Cabbage	2.7	1.4	0.43	37
Cab 27	Cabbage	3.5	1.2	0.51	35.5
Cab 28	Cabbage	3	1.3	0.21	32
Cab 28	Cabbage	3.1	2.2	0.15	20
Cab 29	Cabbage	2.6	1	0.098	35.3
Cab 29	Cabbage	3	1.6	0.11	37.5
Cab 30	Cabbage	2.6	1	0.15	38.8
Cab 30	Cabbage	3	1.3	0.26	41
Cab 30	Cabbage	3.7	1.3	0.18	53.4
Cab 31	Cabbage	2.8	1	0.26	23
Cab 32	Cabbage	2.9	1.1	0.46	49.8
Cab 32	Cabbage	2.5	1.6	0.47	49.6
Cab 32	Cabbage	2.7	0.21	0.59	32
Cab 33	Cabbage	2.8	0.7	0.32	24.8
Cab 33	Cabbage	3.8	1.4	0.21	24.5
Cab 34	Cabbage	2.8	0.7	0.21	61.5
Cab 34	Cabbage	3.2	1.4	0.2	28.5
Cab 35	Cabbage	2.6	1	0.18	29
Cab 35	Cabbage	3.1	2.2	0.31	41.1
Cab 36	Cabbage	2.7	1.2	0.097	49.4
Cab 36	Cabbage	2.8	1.8	0.25	50.9
Cab 36	Cabbage	3.7	1.3	0.27	43.6
Cab 37	Cabbage	2.6	0.96	0.21	38.1
Cab 37	Cabbage	3.2	1.4	0.12	49.5
Cab 37	Cabbage	3.6	1.1	0.18	52.4
Cau 38	Cauliflower	2.7	0.92	0.078	19
Cau 38	Cauliflower	2.9	0.41	0.18	17.4
Cau 38	Cauliflower	3.7	1.3	0.11	25.4
Cau 39	Cauliflower	2.8	0.96	0.17	27.9
Cau 39	Cauliflower	2.9	1.2	0.18	39.4
Cau 39	Cauliflower	3.2	0.77	0.43	28.8
Cau 40	Cauliflower	2.7	1.1	0.13	22
Cau 40	Cauliflower	2.7	1.3	0.28	30.1
Cau 40	Cauliflower	3.5	1.5	0.17	31
Cau 41	Cauliflower	2.7	1.4	0.073	25
Cau 41	Cauliflower	3	1.6	0.12	36.8
Cau 41	Cauliflower	2.9	1.4	0.75	30.6
Cau 42	Cauliflower	2.8	0.96	0.16	20
Cau 42	Cauliflower	2.8	1.2	0.3	17
Cau 43	Cauliflower	3	1.3	0.077	16

Cau 43	Cauliflower	3.2	1.3	0.14	11
Cau 44	Cauliflower	3	1.3	0.097	29.6
Cau 44	Cauliflower	2.7	0.56	0.29	23
Cau 44	Cauliflower	2.9	1.4	0.52	36.7
Cau 46	Cauliflower	2.8	0.7	0.081	35.4
Cau 46	Cauliflower	3.5	1.5	0.1	86
Ca 47	Cauliflower	2.8	0.7	0.3	45.8
Ca 47	Cauliflower	2.7	1	0.15	48
Cau 48	Cauliflower	2.7	1.1	0.1	30.6
Cau 49	Cauliflower	2.6	0.96	0.089	29.7
Cau 49	Cauliflower	2.7	1	0.14	32.3
Cau 49	Cauliflower	2.9	1.5	0.22	39.7
Ka 51	Kale	3	1.3	0.11	23.1
Ka 52	Kale	2.6	0.96	0.12	33.2
Ka 53	Kale	2.9	1.1	0.16	40.3
Ka 53	Kale	3.2	1.4	0.2	30.8
Ka 53	Kale	2.9	1.4	0.11	26.7
Ka 54	Kale	2.7	1.3	0.39	39
Ka 54	Kale	3.1	2.2	0.2	43.6
Ka 54	Kale	3.5	1.2	0.35	31
Ka 55	Kale	2.9	1.1	0.17	45.7
Ka 55	Kale	3.5	1.2	0.39	46.6
Ka 56	Kale	2.8	0.7	0.14	27
Ka 56	Kale	3	1.6	0.24	45.3
Ka 56	Kale	4.1	2.4	0.23	43.8
Ko 59	Kohlrabi	2.7	0.92	0.21	36.9
Ko 59	Kohlrabi	2.7	1	0.29	42.9
Ko 60	Kohlrabi	2.6	1.4	0.3	34.8
Ko 60	Kohlrabi	4.1	2.4	0.41	52.1
Ko 61	Kohlrabi	2.7	1.3	0.15	22.9
Ko 61	Kohlrabi	4.7	1	0.36	24.8
Ko 63	Kohlrabi	2.7	1.4	0.13	21
Ko 64	Kohlrabi	2.7	0.92	0.21	22.2
Ko 64	Kohlrabi	2.8	1.2	0.27	24.9
Ko 64	Kohlrabi	2.7	1.3	0.18	26.1
Ko 65	Kohlrabi	2.8	0.98	0.24	22.5
Ko 65	Kohlrabi	3	1.3	0.42	25
Ko 65	Kohlrabi	3.5	1.2	0.34	22
Sa Ca 66	Savoy cabbage	2.6	1	0.37	35.2
Sa Ca 66	Savoy cabbage	2.7	1.3	0.42	43.8
Sa Ca 66	Savoy cabbage	2.8	1	0.41	33.4
Sa Ca 67	Savoy cabbage	2.7	0.92	0.16	31.4
Sa Ca 67	Savoy cabbage	2.9	1.6	0.17	49.6
Sa Ca 67	Savoy cabbage	3.4	1.4	0.34	39.8
Sa Ca 68	Savoy cabbage	2.7	1.3	0.15	35.3
Sa Ca 68	Savoy cabbage	2.5	1.6	0.12	41.6
Sa Ca 68	Savoy cabbage	4.1	2.4	0.17	57.6
Sa Ca 69	Savoy cabbage	2.9	1.1	0.28	22
Sa Ca 70	Savoy cabbage	2.8	0.7	0.23	75.4
Sa Ca 70	Savoy cabbage	2.7	0.56	0.38	66.6
Sa Ca 70	Savoy cabbage	2.7	0.21	0.29	33.4

Sa Ca 71	Savoy cabbage	3.5	1	0.13	50
Sa Ca 72	Savoy cabbage	2.6	0.96	0.3	42.3
Sa Ca 72	Savoy cabbage	3	1.6	0.31	48.8
Sa Ca 73	Savoy cabbage	2.7	1.3	0.26	46
Sa Ca 73	Savoy cabbage	2.8	1.5	0.34	47.1
Sa Ca 73	Savoy cabbage	2.7	1.3	0.29	38.6
Sa Ca 74	Savoy cabbage	2.7	1.2	0.29	74.7
Sa Ca 74	Savoy cabbage	2.7	0.56	0.3	40.8
Sa Ca 74	Savoy cabbage	3.2	0.77	0.33	52.8
Cab 75	Cabbage	2.7	1.3	0.17	46
Cab 75	Cabbage	3.1	1.3	0.17	67.5
Cab 75	Cabbage	2.7	0.21	0.56	58.8
Cab 75	Cabbage	3	1.3	0.095	32.4
Cab 75	Cabbage	2.5	1.6	0.15	37.9
Cab 75	Cabbage	3.5	1	0.12	27.4
Sa Ca 76	Savoy cabbage	2.6	1.4	0.11	49.9
Sa Ca 76	Savoy cabbage	2.9	1.6	0.097	44.8
Sa Ca 76	Savoy cabbage	3.2	1.3	0.15	44

Cs-137_ concentration_ ratio	Sr-90_ concentration_ ratio	Plant_dry _weight_ g
0.06	21.14	39
0.06	31.81	31
0.04	25.07	41.2
0.1	30.91	4.8
0.13	29.85	38.5
0.15	43.23	119.8
0.1	44.9	68.3
0.08	38.27	51
0.08	31	32.2
0.04	23.45	31.7
0.05	22.21	47.4
0.06	20.64	49.6
0.04	24.88	23.3
0.07	29.35	30.5
0.09	24.58	29.8
0.11	30.89	49.4
0.04	28.9	28.1
0.03	21.77	18.8
0.05	22.87	23.2
0.06	19.21	68.4
0.05	15.71	12.7
0.06	13.56	79.9
0.04	14.54	35.4
0.06	26.15	23.3
0.07	22.92	78
0.05	24.69	36
0.07	26.25	106
0.06	22.15	19.7
0.08	22.19	45.8
0.05	22.1	62.5
0.08	18.57	12.9
0.13	25.7	76.8
0.08	27.08	12.02
0.07	27.21	51.9
0.1	26.4	13.3
0.1	32.08	73.1
0.1	24.04	22.6
0.06	81.36	14.7
0.07	40.75	50.1
0.03	32.6	21.4
0.09	29.35	32.7
0.09	33.54	89.1
0.08	25.67	8.4
0.11	24.17	9
0.07	24.15	23.3
0.08	23.29	57

0.12	28.46	8.6
0.13	31	35.9
0.05	57.86	50.9
0.1	32.73	34.9
0.04	35.4	25.1
0.05	30.64	42.8
0.05	39.46	58.2
0.04	48	11.9
0.15	40.21	66.3
0.12	44	58.5
0.19	35.64	43.1
0.16	26.43	9.4
0.15	29.58	27.9
0.07	24.62	2.3
0.05	9.09	11
0.04	35.3	47.2
0.04	23.44	41.7
0.06	38.8	48.2
0.09	31.54	11.4
0.05	41.08	20.2
0.09	23	8.6
0.16	45.27	52
0.19	31	38.7
0.22	152.38	10.2
0.11	35.43	40.2
0.06	17.5	11.1
0.08	87.86	21
0.06	20.36	31.7
0.07	29	2.5
0.1	18.68	69.4
0.04	41.17	36.5
0.09	28.28	23
0.07	33.54	31.2
0.08	39.69	60
0.04	35.36	22.5
0.05	47.64	26.2
0.03	20.65	11.7
0.06	42.44	72.2
0.03	19.54	49.2
0.06	29.06	91.9
0.06	32.83	30.5
0.13	37.4	30
0.05	20	15.6
0.1	23.15	24.9
0.05	20.67	12.5
0.03	17.86	10.4
0.04	23	46.5
0.26	21.86	22.2
0.06	20.83	16.1
0.11	14.17	4.2
0.03	12.31	5.2

0.04	8.46	10.3
0.03	22.77	34.7
0.11	41.07	2.4
0.18	26.21	42.7
0.03	50.57	39.1
0.03	57.33	4.7
0.11	65.43	19.3
0.06	48	11.5
0.04	27.82	38
0.03	30.94	56.1
0.05	32.3	49.1
0.08	26.47	29.1
0.04	17.77	33.3
0.05	34.58	46.7
0.06	36.64	37.9
0.06	22	45.9
0.04	19.07	45.1
0.14	30	1.8
0.06	19.82	24.2
0.1	25.83	14.6
0.06	41.55	35.3
0.11	38.83	45
0.05	38.57	9.5
0.08	28.31	24
0.06	18.25	78
0.08	40.11	35.2
0.11	42.9	36
0.12	24.86	69.6
0.1	21.71	27.9
0.06	17.62	43.3
0.08	24.8	38.5
0.05	15	11.9
0.08	24.13	30.8
0.1	20.75	27.5
0.07	20.08	15.9
0.09	22.96	19.3
0.14	19.23	124.5
0.1	18.33	7.8
0.14	35.2	14.7
0.16	33.69	14.1
0.15	33.4	60
0.06	34.13	45.9
0.06	31	74.4
0.1	28.43	38.8
0.06	27.15	34.7
0.05	26	34.3
0.04	24	32.4
0.1	20	14.3
0.08	107.71	50.7
0.14	118.93	62.8
0.11	159.05	39.3

0.04	50	25
0.12	44.06	63.7
0.1	30.5	36.6
0.1	35.38	72.2
0.12	31.4	43.5
0.11	29.69	42.3
0.11	62.25	49.2
0.11	72.86	50.1
0.1	68.57	31.8
0.06	35.38	1
0.05	51.92	29.7
0.21	280	67.9
0.03	24.92	42
0.06	23.69	44
0.03	27.4	43.2
0.04	35.64	37.2
0.03	28	32.6
0.05	33.85	25.5

Experiment 1 (Growth chamber)

Cultivar	Morphotype	Harvest_ number	Soil_Cs-134 _KBq kg-1_(d. wt)	Plant_Cs-134 _KBq kg-1_(d. wt)	Cs-134 _concentration_ ratio
Bor 4	Borecole	1	15.039	2.736	0.182
Bor 4	Borecole	1	12.141	4.548	0.375
Bor 4	Borecole	1	14.352	2.299	0.160
Bor 4	Borecole	1	15.857	2.987	0.188
Bor 4	Borecole	2	13.719	3.554	0.259
Bor 4	Borecole	2	15.640	4.112	0.263
Bor 4	Borecole	2	14.181	5.059	0.357
Bor 4	Borecole	2	14.701	4.579	0.311
Bor 4	Borecole	3	13.558	3.958	0.292
Bor 4	Borecole	3	20.260	3.549	0.175
Bor 4	Borecole	3	13.435	3.138	0.234
Bor 4	Borecole	3	12.259	3.751	0.306
Bor 4	Borecole	4	10.429	4.268	0.409
Bor 4	Borecole	4	12.128	3.790	0.312
Bor 4	Borecole	4	10.425	2.780	0.267
Bor 4	Borecole	4	13.784	3.166	0.230
Bor 4	Borecole	5	14.013	2.523	0.180
Bor 4	Borecole	5	13.724	2.426	0.177
Bor 4	Borecole	5	11.049	3.180	0.288
Bor 4	Borecole	5	12.701	2.766	0.218
Bor 4	Borecole	6	12.849	2.892	0.225
Bor 4	Borecole	6	12.032	2.987	0.248
Bor 4	Borecole	6	10.719	3.492	0.326
Bor 4	Borecole	6	13.257	3.831	0.289
Bor 4	Borecole	7	11.410	2.259	0.198
Bor 4	Borecole	7	13.215	2.535	0.192
Bor 4	Borecole	7	11.795	3.737	0.317
Bor 4	Borecole	7	12.144	4.558	0.375
Bor 4	Borecole	8	10.123	6.857	0.677
Bor 4	Borecole	8	9.131	2.942	0.322
Bor 4	Borecole	8	9.707	6.344	0.654
Bor 4	Borecole	8	9.570	4.816	0.503
Bro 12	Broccoli	1	14.994	2.823	0.188
Bro 12	Broccoli	1	12.469	6.336	0.508
Bro 12	Broccoli	1	9.474	3.186	0.336
Bro 12	Broccoli	1	14.084	2.736	0.194
Bro 12	Broccoli	2	11.823	3.566	0.302
Bro 12	Broccoli	2	11.900	4.090	0.344
Bro 12	Broccoli	2	14.372	5.429	0.378
Bro 12	Broccoli	2	14.598	7.282	0.499
Bro 12	Broccoli	3	13.076	4.892	0.374
Bro 12	Broccoli	3	13.523	3.527	0.261
Bro 12	Broccoli	3	14.291	8.752	0.612
Bro 12	Broccoli	3	11.860	4.602	0.388
Bro 12	Broccoli	4	12.299	1.930	0.157

Bro 12	Broccoli	4	11.824	5.314	0.449
Bro 12	Broccoli	4	13.689	3.246	0.237
Bro 12	Broccoli	4	13.980	2.641	0.189
Bro 12	Broccoli	5	9.449	4.071	0.431
Bro 12	Broccoli	5	9.334	5.012	0.537
Bro 12	Broccoli	5	11.967	3.128	0.261
Bro 12	Broccoli	5	11.941	1.648	0.138
Bro 12	Broccoli	6	11.935	3.518	0.295
Bro 12	Broccoli	6	10.857	4.458	0.411
Bro 12	Broccoli	6	10.641	1.389	0.131
Bro 12	Broccoli	6	10.531	15.735	1.494
Bro 12	Broccoli	7	10.692	2.095	0.196
Bro 12	Broccoli	7	10.948	4.746	0.434
Bro 12	Broccoli	7	8.887	2.996	0.337
Bro 12	Broccoli	7	10.204	4.331	0.424
Bro 12	Broccoli	8	9.006	8.259	0.917
Bro 12	Broccoli	8	9.424	7.340	0.779
Bro 12	Broccoli	8	9.086	7.538	0.830
Br Sp 21	Brussel sprout	1	14.901	5.062	0.340
Br Sp 21	Brussel sprout	1	13.881	3.888	0.280
Br Sp 21	Brussel sprout	1	12.900	4.951	0.384
Br Sp 21	Brussel sprout	1	15.655	4.997	0.319
Br Sp 21	Brussel sprout	2	14.910	2.844	0.191
Br Sp 21	Brussel sprout	2	24.964	3.099	0.124
Br Sp 21	Brussel sprout	2	13.560	2.873	0.212
Br Sp 21	Brussel sprout	2	16.704	4.353	0.261
Br Sp 21	Brussel sprout	3	13.202	4.213	0.319
Br Sp 21	Brussel sprout	3	14.238	1.993	0.140
Br Sp 21	Brussel sprout	3	12.987	9.047	0.697
Br Sp 21	Brussel sprout	3	13.817	4.260	0.308
Br Sp 21	Brussel sprout	4	11.937	3.186	0.267
Br Sp 21	Brussel sprout	4	15.304	4.692	0.307
Br Sp 21	Brussel sprout	4	14.416	3.740	0.259
Br Sp 21	Brussel sprout	4	11.841	2.351	0.199
Br Sp 21	Brussel sprout	5	11.322	4.812	0.425
Br Sp 21	Brussel sprout	5	10.698	1.807	0.169
Br Sp 21	Brussel sprout	5	10.485	3.480	0.332
Br Sp 21	Brussel sprout	5	11.762	3.369	0.286
Br Sp 21	Brussel sprout	6	10.756	2.771	0.258
Br Sp 21	Brussel sprout	6	10.817	3.156	0.292
Br Sp 21	Brussel sprout	6	13.489	4.024	0.298
Br Sp 21	Brussel sprout	6	11.638	1.857	0.160
Br Sp 21	Brussel sprout	7	11.879	4.461	0.376
Br Sp 21	Brussel sprout	7	9.389	3.529	0.376
Br Sp 21	Brussel sprout	7	12.440	1.421	0.114
Br Sp 21	Brussel sprout	7	11.197	1.843	0.165
Br Sp 21	Brussel sprout	8	11.877	2.857	0.241
Br Sp 21	Brussel sprout	8	14.253	2.081	0.146
Br Sp 21	Brussel sprout	8	10.197	0.631	0.062
Br Sp 21	Brussel sprout	8	12.182	5.219	0.428
Cab 31	Cabbage	1	19.592	1.373	0.070

Cab 31	Cabbage	1	13.238	0.929	0.070
Cab 31	Cabbage	1	11.556	1.657	0.143
Cab 31	Cabbage	1	14.380	10.715	0.745
Cab 31	Cabbage	2	13.925	3.100	0.223
Cab 31	Cabbage	2	14.932	4.222	0.283
Cab 31	Cabbage	2	16.324	2.489	0.152
Cab 31	Cabbage	2	15.651	2.245	0.143
Cab 31	Cabbage	3	13.348	1.747	0.131
Cab 31	Cabbage	3	13.121	2.584	0.197
Cab 31	Cabbage	3	12.439	2.081	0.167
Cab 31	Cabbage	3	12.689	4.033	0.318
Cab 31	Cabbage	4	13.713	2.665	0.194
Cab 31	Cabbage	4	11.510	1.742	0.151
Cab 31	Cabbage	4	15.088	1.043	0.069
Cab 31	Cabbage	4	12.261	2.929	0.239
Cab 31	Cabbage	5	12.562	1.617	0.129
Cab 31	Cabbage	5	19.419	2.242	0.115
Cab 31	Cabbage	5	11.240	0.086	0.008
Cab 31	Cabbage	5	12.120	6.177	0.510
Cab 31	Cabbage	6	11.658	4.284	0.367
Cab 31	Cabbage	6	10.193	3.656	0.359
Cab 31	Cabbage	6	11.759	2.832	0.241
Cab 31	Cabbage	6	11.133	2.685	0.241
Cab 31	Cabbage	7	12.491	3.690	0.295
Cab 31	Cabbage	7	11.203	1.673	0.149
Cab 31	Cabbage	7	12.080	0.955	0.079
Cab 31	Cabbage	7	28.468	2.022	0.071
Cab 31	Cabbage	8	13.207	3.380	0.256
Cab 31	Cabbage	8	11.125	4.197	0.377
Cab 31	Cabbage	8	8.768	0.794	0.091
Cab 31	Cabbage	8	11.251	18.024	1.602
Cau 41	Cauliflower	1	25.019	4.676	0.187
Cau 41	Cauliflower	1	15.075	1.866	0.124
Cau 41	Cauliflower	1	12.664	3.283	0.259
Cau 41	Cauliflower	1	11.278	1.616	0.143
Cau 41	Cauliflower	2	13.737	3.764	0.274
Cau 41	Cauliflower	2	12.850	0.526	0.041
Cau 41	Cauliflower	2	15.193	0.991	0.065
Cau 41	Cauliflower	2	12.791	0.840	0.066
Cau 41	Cauliflower	3	11.432	4.389	0.384
Cau 41	Cauliflower	3	15.883	15.072	0.949
Cau 41	Cauliflower	3	12.521	9.073	0.725
Cau 41	Cauliflower	3	12.726	1.465	0.115
Cau 41	Cauliflower	4	11.700	2.375	0.203
Cau 41	Cauliflower	4	11.127	1.623	0.146
Cau 41	Cauliflower	4	11.030	2.832	0.257
Cau 41	Cauliflower	4	12.395	0.955	0.077
Cau 41	Cauliflower	5	11.816	0.994	0.084
Cau 41	Cauliflower	5	11.963	1.612	0.135
Cau 41	Cauliflower	5	13.288	2.574	0.194
Cau 41	Cauliflower	5	12.447	4.261	0.342

Cau 41	Cauliflower	6	10.666	2.860	0.268
Cau 41	Cauliflower	6	10.777	2.742	0.254
Cau 41	Cauliflower	6	9.875	0.995	0.101
Cau 41	Cauliflower	6	12.710	1.224	0.096
Cau 41	Cauliflower	7	13.468	2.916	0.217
Cau 41	Cauliflower	7	11.236	2.807	0.250
Cau 41	Cauliflower	7	10.502	0.604	0.058
Cau 41	Cauliflower	7	11.589	1.652	0.143
Cau 41	Cauliflower	8	11.710	0.616	0.053
Cau 41	Cauliflower	8	11.222	2.370	0.211
Cau 41	Cauliflower	8	13.070	2.216	0.170
Cau 41	Cauliflower	8	9.203	2.322	0.252
Ko 60	Kohlrabi	1	16.444	2.844	0.173
Ko 60	Kohlrabi	1	16.271	2.414	0.148
Ko 60	Kohlrabi	1	12.193	2.045	0.168
Ko 60	Kohlrabi	1	10.900	1.004	0.092
Ko 60	Kohlrabi	2	12.531	3.054	0.244
Ko 60	Kohlrabi	2	13.186	4.397	0.333
Ko 60	Kohlrabi	2	13.675	1.284	0.094
Ko 60	Kohlrabi	2	14.732	1.910	0.130
Ko 60	Kohlrabi	3	19.504	3.970	0.204
Ko 60	Kohlrabi	3	12.584	4.218	0.335
Ko 60	Kohlrabi	3	15.579	1.060	0.068
Ko 60	Kohlrabi	3	13.172	2.211	0.168
Ko 60	Kohlrabi	4	14.282	2.456	0.172
Ko 60	Kohlrabi	4	14.159	3.746	0.265
Ko 60	Kohlrabi	4	13.142	2.669	0.203
Ko 60	Kohlrabi	4	12.534	3.107	0.248
Ko 60	Kohlrabi	5	12.970	0.902	0.070
Ko 60	Kohlrabi	5	10.423	1.827	0.175
Ko 60	Kohlrabi	5	10.686	3.442	0.322
Ko 60	Kohlrabi	5	11.985	2.094	0.175
Ko 60	Kohlrabi	6	11.811	2.207	0.187
Ko 60	Kohlrabi	6	11.405	2.983	0.262
Ko 60	Kohlrabi	6	11.500	2.475	0.215
Ko 60	Kohlrabi	6	10.208	0.865	0.085
Ko 60	Kohlrabi	7	8.870	2.588	0.292
Ko 60	Kohlrabi	7	9.755	3.606	0.370
Ko 60	Kohlrabi	7	10.880	3.789	0.348
Ko 60	Kohlrabi	7	9.747	1.333	0.137
Ko 60	Kohlrabi	8	10.355	1.230	0.119
Ko 60	Kohlrabi	8	8.308	2.158	0.260
Ko 60	Kohlrabi	8	7.756	3.691	0.476
Ko 60	Kohlrabi	8	9.648	0.591	0.061
Ch Ka 50	Chinese kale	1	13.191	2.192	0.166
Ch Ka 50	Chinese kale	1	12.443	0.790	0.063
Ch Ka 50	Chinese kale	1	13.722	3.390	0.247
Ch Ka 50	Chinese kale	1	11.713	0.898	0.077
Ch Ka 50	Chinese kale	2	16.951	2.792	0.165
Ch Ka 50	Chinese kale	2	11.894	0.473	0.040
Ch Ka 50	Chinese kale	2	15.153	1.020	0.067

Ch Ka 50	Chinese kale	2	15.386	1.732	0.113
Ch Ka 50	Chinese kale	3	17.508	1.429	0.082
Ch Ka 50	Chinese kale	3	20.648	1.585	0.077
Ch Ka 50	Chinese kale	3	13.120	1.895	0.144
Ch Ka 50	Chinese kale	3	12.345	7.305	0.592
Ch Ka 50	Chinese kale	4	12.363	3.369	0.272
Ch Ka 50	Chinese kale	4	16.122	0.643	0.040
Ch Ka 50	Chinese kale	4	12.515	0.877	0.070
Ch Ka 50	Chinese kale	4	14.492	3.841	0.265
Ch Ka 50	Chinese kale	5	11.482	1.395	0.121
Ch Ka 50	Chinese kale	5	11.306	3.105	0.275
Ch Ka 50	Chinese kale	5	12.325	2.139	0.174
Ch Ka 50	Chinese kale	5	11.860	2.411	0.203
Ch Ka 50	Chinese kale	6	11.870	0.720	0.061
Ch Ka 50	Chinese kale	6	9.918	0.811	0.082
Ch Ka 50	Chinese kale	6	15.423	0.876	0.057
Ch Ka 50	Chinese kale	6	12.527	1.883	0.150
Ch Ka 50	Chinese kale	7	12.555	0.853	0.068
Ch Ka 50	Chinese kale	7	9.762	1.732	0.177
Ch Ka 50	Chinese kale	7	11.499	1.753	0.152
Ch Ka 50	Chinese kale	7	14.519	2.888	0.199
Ch Ka 50	Chinese kale	8	9.188	4.032	0.439
Ch Ka 50	Chinese kale	8	8.805	3.873	0.440
Ch Ka 50	Chinese kale	8	7.834	3.794	0.484
Ch Ka 50	Chinese kale	8	9.545	2.301	0.241
Sa Ca 69	Savoy cabbage	1	13.513	1.976	0.146
Sa Ca 69	Savoy cabbage	1	11.502	1.996	0.174
Sa Ca 69	Savoy cabbage	1	15.761	1.978	0.125
Sa Ca 69	Savoy cabbage	1	11.575	2.519	0.218
Sa Ca 69	Savoy cabbage	2	13.326	1.833	0.138
Sa Ca 69	Savoy cabbage	2	13.373	1.497	0.112
Sa Ca 69	Savoy cabbage	2	12.487	2.648	0.212
Sa Ca 69	Savoy cabbage	2	14.357	3.201	0.223
Sa Ca 69	Savoy cabbage	3	16.803	1.911	0.114
Sa Ca 69	Savoy cabbage	3	10.660	2.290	0.215
Sa Ca 69	Savoy cabbage	3	16.276	6.202	0.381
Sa Ca 69	Savoy cabbage	3	12.357	2.402	0.194
Sa Ca 69	Savoy cabbage	4	12.744	1.713	0.134
Sa Ca 69	Savoy cabbage	4	11.135	0.471	0.042
Sa Ca 69	Savoy cabbage	4	12.201	2.712	0.222
Sa Ca 69	Savoy cabbage	4	13.473	7.844	0.582
Sa Ca 69	Savoy cabbage	5	16.493	1.710	0.104
Sa Ca 69	Savoy cabbage	5	10.616	4.459	0.420
Sa Ca 69	Savoy cabbage	5	9.945	1.708	0.172
Sa Ca 69	Savoy cabbage	5	15.826	4.117	0.260
Sa Ca 69	Savoy cabbage	6	12.026	2.111	0.176
Sa Ca 69	Savoy cabbage	6	10.319	1.991	0.193
Sa Ca 69	Savoy cabbage	6	11.487	4.487	0.391
Sa Ca 69	Savoy cabbage	6	11.197	0.527	0.047
Sa Ca 69	Savoy cabbage	7	12.711	0.496	0.039
Sa Ca 69	Savoy cabbage	7	9.228	2.142	0.232

Sa Ca 69	Savoy cabbage	7	9.827	2.012	0.205
Sa Ca 69	Savoy cabbage	7	11.278	3.762	0.334
Sa Ca 69	Savoy cabbage	8	9.774	3.128	0.320
Sa Ca 69	Savoy cabbage	8	8.342	2.114	0.253
Sa Ca 69	Savoy cabbage	8	6.888	1.387	0.201
Sa Ca 69	Savoy cabbage	8	9.248	3.178	0.344

Plant_dry-weight_g
0.029
0.015
0.008
0.008
0.036
0.035
0.026
0.017
0.098
0.083
0.013
0.047
0.375
0.113
0.182
0.066
0.529
0.099
0.174
0.207
0.654
0.293
0.519
0.236
0.424
0.646
0.544
0.414
1.730
2.649
3.404
3.668
0.020
0.021
0.020
0.020
0.027
0.059
0.041
0.049
0.059
0.071
0.094
0.064
0.180

0.137
0.139
0.140
0.495
0.281
0.227
0.247
0.225
0.499
0.228
0.407
2.283
0.637
0.547
0.730
4.031
4.392
4.827
0.010
0.009
0.010
0.006
0.016
0.048
0.031
0.012
0.049
0.080
0.055
0.029
0.190
0.122
0.174
0.106
0.551
0.325
0.108
0.248
0.350
0.384
0.418
0.373
0.180
0.414
0.710
0.224
5.328
3.020
2.082
3.349
0.022

0.010
0.010
0.013
0.052
0.032
0.024
0.026
0.011
0.085
0.027
0.033
0.025
0.146
0.153
0.113
0.368
0.237
0.342
0.117
0.621
0.287
0.266
0.195
0.329
0.203
0.259
0.070
6.003
3.160
4.565
2.459
0.003
0.008
0.010
0.004
0.015
0.038
0.033
0.011
0.021
0.056
0.061
0.041
0.195
0.103
0.137
0.095
0.083
0.099
0.201
0.227

0.263
0.278
0.269
0.237
0.152
0.198
0.323
0.172
1.725
2.684
1.770
3.392
0.021
0.019
0.024
0.018
0.072
0.084
0.039
0.031
0.047
0.030
0.057
0.061
0.331
0.212
0.138
0.193
0.534
0.165
0.460
0.178
0.591
0.179
0.553
0.664
0.299
0.424
0.244
0.288
2.867
1.912
2.863
2.744
0.022
0.001
0.005
0.009
0.027
0.061
0.037

0.042
0.049
0.075
0.093
0.041
0.037
0.100
0.267
0.040
0.465
0.111
0.125
0.209
0.289
0.255
0.489
0.351
0.212
1.645
0.201
0.072
1.403
2.145
1.919
2.380
0.011
0.012
0.014
0.015
0.051
0.016
0.034
0.014
0.011
0.021
0.015
0.017
0.072
0.126
0.172
0.123
0.152
0.420
0.292
0.166
0.754
0.323
0.473
0.358
0.243
1.165

0.382
0.542
2.826
3.639
3.391
2.959

Supplementary information

Table S1 Cultivars grown in Experiments 3 and 4

Cultivar number	Morphotype
Bor 1	Borecole
Bor 2	Borecole
Bor 3	Borecole
Bor 5	Borecole
Bor 6	Borecole
Bor 4[$]	Borecole
Bro 7	Broccoli
Bro 8	Broccoli
Bro 9	Broccoli
Bro 10	Broccoli
Bro 11	Broccoli
Bro 12	Broccoli
Bro 13	Broccoli
Bro 14	Broccoli
Bro 15	Broccoli
Bro 16	Broccoli
BrSp 17	Brussels sprout
BrSp 18	Brussels sprout
BrSp 19	Brussels sprout
BrSp 20	Brussels sprout
BrSp 21	Brussels sprout
BrSp 22	Brussels sprout
BrSp 23	Brussels sprout
Cab 24	Cabbage
Cab 25	Cabbage
Cab 26	Cabbage
Cab 27	Cabbage
Cab 28	Cabbage
Cab 29	Cabbage
Cab 30	Cabbage
Cab 31	Cabbage
Cab 32	Cabbage
Cab 33	Cabbage
Cab 34	Cabbage
Cab 35	Cabbage
Cab 36	Cabbage
Cab 37	Cabbage
Cab 75[#]	Cabbage
Cau 38	Cauliflower
Cau 39	Cauliflower

Cau 41	Cauliflower
Cau 42	Cauliflower
Cau 43	Cauliflower
Cau 44	Cauliflower
Cau 46	Cauliflower
Cau 47	Cauliflower
Cau 48	Cauliflower
Cau 49	Cauliflower
Cau 40#	Cauliflower
ChKa 50	Chinese kale
Ka 51	Kale
Ka 52	Kale
Ka 53	Kale
Ka 54	Kale
Ka 55	Kale
Ka 56	Kale
Ko 59	Kohlrabi
Ko 60	Kohlrabi
Ko 61	Kohlrabi
Ko 64	Kohlrabi
Ko 65	Kohlrabi
Ko 57$%	Kohlrabi
Ko 58$%	Kohlrabi
Ko 62$%	Kohlrabi
Ko 63#	Kohlrabi
SaCa 66	Savoy cabbage
SaCa 67	Savoy cabbage
SaCa 68	Savoy cabbage
SaCa 69	Savoy cabbage
SaCa 70	Savoy cabbage
SaCa 71	Savoy cabbage
SaCa 72	Savoy cabbage
SaCa 73	Savoy cabbage
SaCa 74	Savoy cabbage
SaCa 76#	Savoy cabbage

$ Denotes cultivars grown only in Experiment 3
 # Denotes cultivars grown only in Experiment4
%Denotes genebank accessions. All other cultivars are commercially available.

Table S2 Cultivars grown in Experiment 1

Cultivar number	Morphotype
Bor 4	Borecole
Bro 12	Broccoli
BrSp 21	Brussels sprout

Cab 31	Cabbage
Cau 41	Cauliflower
ChKa 50	Chinese Kale
Ko 60	Kohlrabi
SaCa 69	Savoy Cabbage

Table S3 Cultivars grown in Experiment 2

Cultivar number	Type
Bor 4*	Borecole
Bro 15	Broccoli
Bro 13	Broccoli
Bro 12*	Broccoli
Bro 10	Broccoli
Bro 11	Broccoli
Br Sp 17	Brussels Sprout
Br Sp 23	Brussels Sprout
Br Sp 20	Brussels Sprout
Br Sp 18	Brussels Sprout
Br Sp 21*	Brussels Sprout
Cab 36	Cabbage
Cab 28	Cabbage
Cab 37	Cabbage
Cab 24	Cabbage
Cab 26	Cabbage
Cab 31*	Cabbage
Cab 32	Cabbage
Cau 41*	Cauliflower
Cau 44	Cauliflower
Cau 43	Cauliflower
Ch Ka 50	Chinese Kale
Ka 53	Kale
Ka 52	Kale
Ko 60*	Kohlrabi
Sa Ca 71	Savoy cabbage
Sa Ca 69*	Savoy cabbage

** Denotes cultivars that are in both Experiment 1 and Experiment 2*

Table S4 Standard codes and references for soil characteristic tests

Soil characteristic	Standard code	Reference
pH (H_2O)	GOST 26423-85	Methods for determination of specific electric conductivity, pH and solid residue of water extract. – State

		standard of USSR. Official Issue. Moscow. Standards Press. 1985. 6p. (Russian)
Cation exchange capacity	GOST 17.4.4.01-84	Nature protection. Soils. Methods for determining the capacity of cation exchange. – Interstate standard. Official Issue. Moscow, STANDARTINFORM, 2008. 6p. (Russian)
Exchangeable P	DSTU 4405:2005	Determination of mobile compounds of phosphorus and potassium by Kirsanov method modified by NSC ISSAR. – National standard of Ukraine. Official issue. Kyiv, DERZHSPOZHIVTANDART UKRAINY, 2006. 8p. (Ukrainian)
Exchangeable K	DSTU 4405:2005	
Exchangeable Ca	GOST 26487-85	Determination of exchangeable calcium and exchangeable (mobile) magnesium by CINAO methods. – State standard of USSR. Official Issue. Moscow. Standards Press. 1985. 13p. (Russian)
Exchangeable Mg	GOST 26487-85	
Organic matter content	DSTU 4289:2004	Methods for determination of organic matter. – National standard of Ukraine. Official issue. Kyiv, DERZHSPOZHIVTANDART UKRAINY, 2005. 11p. (Ukrainian)
Clay content	GOST 12536-79	Methods of laboratory granulometric (grain-size) and microaggregate distribution. – Interstate standard. Official Issue. Moscow, STANDARTINFORM, 2008. 17p. (Russian)