

## ANALYSIS OF PESTICIDE USAGE SURVEY

The aim of the analysis of the results was to provide an estimate of the pesticide usage associated with by crop type within each region and nationally.

Estimates are derived from pesticide usage survey data which are stratified by region and holding size within each crop type. The survey reports the mass of pesticide applied and the area to which it is applied. The survey information is combined with the total cultivated area within each stratum to provide an estimate of the total mass of pesticide used on that crop type by region and nationally, and of the area sprayed. Each estimate ( $E$ ) is provided with a standard error ( $se$ ). In general we expect, with approximately 95% confidence, that the true quantity of pesticide used will lie within the interval:

$$E \pm 1.96 \times se$$

### Estimation method

We are provided with information about holdings in  $J$  regions. Holdings are assigned one of  $K$  size classes.  $L$  holdings are surveyed within each stratum ( $j,k$ ). In addition the total area and number of holdings in each stratum from which samples have been taken is reported. Hence, we are given:

$H_{j,k}$ : the total area of the stratum (in holdings of size class  $k$ , in region  $j$ )

$N_{j,k}$ : the total number of holdings in the stratum

$L_{j,k}$ : number of holdings surveyed within the stratum

$h_{j,k,l}$ : area of each holding surveyed within the stratum

$a_{l,j,k,l}$ : area of each holding sprayed within the surveyed stratum

$m_{j,k,l}$ : mass of pesticide applied to each holding in the surveyed stratum

Then we estimate:

$r_{a,j,k}$ : mean area sprayed per area surveyed within the stratum

$r_{m,j,k}$ : mean mass applied per area surveyed within the stratum

$s_{a_{j,k}}$ : the between-holding standard deviation of the area sprayed per area surveyed within the stratum

$s_{m_{j,k}}$ : the between holding standard deviation of the mass sprayed per area surveyed within the stratum

$A_j$ : estimated total area sprayed in a region

$se_{A_j}$ : standard error of estimated total area sprayed in a region

$M_j$ : estimated total mass applied in a region

$se_{M_j}$ : standard error of estimated total mass applied in a region

$A$ : estimated total area sprayed nationally

$se_A$ : standard error of estimated total area sprayed nationally

$M$ : estimated total mass applied nationally

$se_M$ : standard error of estimated total mass applied nationally

Estimates are provided using the following formulas

## Estimators

$$r_{a_{j,k,l}} = \frac{a_{j,k,l}}{h_{j,k,l}} \quad \text{Equation 1}$$

$$r_{m_{j,k,l}} = \frac{m_{j,k,l}}{h_{j,k,l}} \quad \text{Equation 2}$$

$$r_{a_{j,k}} = \text{mean}(r_{a_{j,k,l}}), l = 1, 2 \dots L_{j,k} \quad \text{Equation 3}$$

$$r_{m_{j,k}} = \text{mean}(r_{m_{j,k,l}}), l = 1, 2 \dots L_{j,k} \quad \text{Equation 4}$$

$$s_{a_{j,k}} = \text{sd}(r_{a_{j,k,l}}), l = 1, 2 \dots L_{j,k} \quad \text{Equation 5}$$

$$s_{m_{j,k}} = \text{sd}(r_{m_{j,k,l}}), l = 1, 2 \dots L_{j,k} \quad \text{Equation 6}$$

$$A_j = \sum_{k=1}^{k=K} H_{j,k} \cdot r_{a_{j,k}} \quad \text{Equation 7}$$

$$M_j = \sum_{k=1}^{k=K} H_{j,k} \cdot r_{m_{j,k}} \quad \text{Equation 8}$$

$$se_{A_j} = \sqrt{\sum_{k=1}^{k=K} H_{j,k}^2 \cdot \frac{s_{a_{j,k}}^2}{L_{j,k}} \cdot \frac{N_{j,k} - L_{j,k}}{N_{j,k} - 1}} \quad \text{Equation 9}$$

$$se_{M_j} = \sqrt{\sum_{k=1}^{k=K} H_{j,k}^2 \cdot \frac{s_{m_{j,k}}^2}{L_{j,k}} \cdot \frac{N_{j,k} - L_{j,k}}{N_{j,k} - 1}} \quad \text{Equation 10}$$

$$A = \sum_{j=1}^{j=J} A_j \quad \text{Equation 11}$$

$$M = \sum_{j=1}^{j=J} M_j \quad \text{Equation 12}$$

$$se_A = \sqrt{\sum_{j=1}^{j=J} se_{A_j}^2} \quad \text{Equation 13}$$

$$se_M = \sqrt{\sum_{j=1}^{j=J} se_{M_j}^2} \quad \text{Equation 14}$$

Standard errors  $se_A$ ,  $se_M$ ,  $se_{A_j}$  and  $se_{M_j}$  are estimated by a first order Taylor approximation [i] (Equations 9,10,13,14) with a finite population correction [ii] (Equations 9 and 10)

95% confidence intervals for estimates  $A_j$ ,  $M_j$ ,  $A$  and  $M$  as estimated as  $\text{mean} \pm 1.96 \times \text{standard error}$ .

Estimates of use derived from this survey were based on a stratification by region only because of a number of strata (region and size) which contained no holdings or a low number of holdings (less than 5). One survey entry for potatoes in Northern Ireland and one from Scotland each with a crop area of zero was removed from the data. Estimates of the use of pesticides on sugar beet and potatoes in Wales each based on a survey of a single holding were not included in the estimates. Upper and lower confidence intervals were not reported where the relative standard error was estimated to be larger than 30%

Estimates of area of application and mass applied by crop (including the total for all arable crops) and region are provided in Tables 1 and 2. Estimates of the total area of application and mass applied for each crop and for all arable crops are given in tables 3 and 4.

## Assumptions

- 1) The survey is unbiased. This means that there is no correlation between the use of pesticides on the holding and the probability of holdings being included or excluded from a survey. The simplest way of achieving this is to sample holdings at random from the population of holdings within a stratum.
- 2) Samples are not correlated between strata. This means that if by chance the holdings sampled from one stratum have a higher average pesticide use than the population within the stratum, then this provides no information about the relation between samples and populations in other strata.
- 3) The values of number of holdings per strata are correct.
- 4) The size of the potential error in estimates of the total area of holdings [se(H)] within each stratum is small compared with the standard error of the estimates for the ratios “mean area sprayed per area surveyed within the stratum” and “mean mass applied per area surveyed within the stratum” [se(R)]. For uncorrelated errors “small” might mean  $rse(H) < 0.3 \times rse(R)$ <sup>1</sup>
- 5) The error associated with estimates  $A_j$ ,  $M_j$ ,  $A$ , and  $M$  is assumed to be described by a normal distribution

## Independent annual samples v sampling from a panel

There is no particular reason why moving from taking a sample each year to sampling from a panel should require any change in the method used to estimate the quantity of pesticides used and their standard errors as long as assumptions 1 to 4 continue to hold.

The survey company has indicated that it is possible that farms that have a very low use of products, such as organic farms, may decline to take part in surveys more often than other farms. We don't know whether this is a particular issue with their panel surveys, or whether it has an appreciable effect.

---

<sup>1</sup> If given estimates of relative standard errors (rse)  $rse(R)=1$  and  $rse(H)=0.3$  then  $rse(R.H)=1.04$

Table 1: Estimates of area of application by crop and region

Crop	Region	Total area	Number of holdings	Number of holdings surveyed	Estimate (Ha)	s.e (Ha)	RSE (%)	95% C.I. (Ha)	
sugar beet	East Midlands	19964	940	32	201154	11897	5.9	177836	224471
sugar beet	Eastern	53618	2123	65	614491	26172	4.3	563193	665789
sugar beet	Yorks. & the Humber	6407	466	4	48670	8597	17.7	31819	65520
potatoes ware	East Midlands	662	256	18	16109	1474	9.2	13220	18998
potatoes ware	Eastern	4449	477	24	102803	7376	7.2	88346	117260
potatoes ware	London & SE	342	75	2	8340	548	6.6	7267	9414
potatoes ware	North East	100	27	2	2050	1030	50.2	NA	NA
potatoes ware	North West	759	264	2	17197	896	5.2	15440	18953
potatoes ware	Northern Ireland	3374	454	40	52165	2280	4.4	47697	56634
potatoes ware	Scotland	14766	1680	46	322905	10292	3.2	302732	343078
potatoes ware	South West	1462	273	6	36469	4959	13.6	26749	46188
potatoes ware	West Midlands	1493	284	9	42218	3633	8.6	35097	49340
potatoes ware	Yorks. & the Humber	936	288	11	23396	1475	6.3	20504	26287
oilseed rape	East Midlands	139411	2964	116	1540971	38296	2.5	1465910	1616031
oilseed rape	Eastern	129945	3171	123	1420690	43553	3.1	1335327	1506053
oilseed rape	London & SE	71462	1577	63	842028	36128	4.3	771216	912839
oilseed rape	North East	23506	735	22	168049	16118	9.6	136457	199641
oilseed rape	North West	4963	256	4	35791	10940	30.6	NA	NA
oilseed rape	Northern Ireland	552	45	13	3093	349	11.3	2410	3777
oilseed rape	Scotland	30141	1036	78	246889	8192	3.3	230832	262946
oilseed rape	South West	50134	1515	43	530276	25010	4.7	481257	579295
oilseed rape	Wales	5080	154	2	53642	1386	2.6	50925	56360
oilseed rape	West Midlands	49075	1716	41	377540	27725	7.3	323199	431881
oilseed rape	Yorks. & the Humber	74309	2431	71	714277	31258	4.4	653011	775543
winter barley	East Midlands	49331	1932	58	493895	20327	4.1	454053	533736
winter barley	Eastern	89775	2846	108	906984	27273	3.0	853528	960440
winter barley	London & SE	36415	1225	51	397801	17711	4.5	363087	432515
winter barley	North East	28748	1019	26	213559	14905	7.0	184345	242774
winter barley	North West	16383	1052	13	128976	7798	6.0	113692	144259
winter barley	Northern Ireland	7628	691	133	62937	1826	2.9	59357	66517
winter barley	Scotland	48030	2009	96	493494	13602	2.8	466834	520154
winter barley	South West	48869	2607	48	522378	24523	4.7	474314	570443

winter barley	Wales	8131	657	8	48972	3733	7.6	41654	56290
winter barley	West Midlands	35087	1880	34	287798	14454	5.0	259467	316128
winter barley	Yorks. & the Humber	71044	2953	76	626778	23594	3.8	580534	673022
spring barley	East Midlands	60087	2161	74	423167	17121	4.0	389610	456725
spring barley	Eastern	89247	3079	98	582345	22761	3.9	537733	626958
spring barley	London & SE	66092	1672	53	553684	27471	5.0	499842	607526
spring barley	North East	12272	595	15	78680	8495	10.8	62029	95331
spring barley	North West	24073	1556	14	103886	11074	10.7	82182	125591
spring barley	Northern Ireland	14708	1608	162	93535	2854	3.1	87942	99129
spring barley	Scotland	238900	7154	240	1417905	25712	1.8	1367509	1468301
spring barley	South West	85290	3957	56	566163	28771	5.1	509773	622554
spring barley	Wales	13758	1341	12	57125	3831	6.7	49616	64635
spring barley	West Midlands	28499	1718	13	168667	16385	9.7	136552	200781
spring barley	Yorks. & the Humber	50046	2507	47	331704	16829	5.1	298719	364688
wheat	East Midlands	335039	4822	139	4644256	113327	2.4	4422134	4866378
wheat	Eastern	467515	6250	187	6788693	134927	2.0	6524236	7053150
wheat	London & SE	218759	3308	102	3220744	99149	3.1	3026413	3415076
wheat	North East	67600	1290	29	770297	43110	5.6	685802	854793
wheat	North West	37315	1438	10	317661	38108	12.0	242968	392353
wheat	Northern Ireland	8616	659	119	83516	2513	3.0	78591	88441
wheat	Scotland	109593	2846	171	1435902	28060	2.0	1380903	1490900
wheat	South West	159035	4266	72	2029244	74732	3.7	1882769	2175719
wheat	Wales	21411	623	8	183268	34112	18.6	116408	250128
wheat	West Midlands	163494	3723	60	1907170	63358	3.3	1782988	2031353
wheat	Yorks. & the Humber	234960	4388	87	2829111	81426	2.9	2669517	2988705
<b>all arable</b>	<b>East Midlands</b>	<b>687630</b>	<b>5915</b>	<b>142</b>	<b>8151812</b>	<b>209381</b>	<b>2.6</b>	<b>7741424</b>	<b>8562199</b>
<b>all arable</b>	<b>Eastern</b>	<b>970309</b>	<b>7515</b>	<b>196</b>	<b>11783584</b>	<b>259682</b>	<b>2.2</b>	<b>11274608</b>	<b>12292560</b>
<b>all arable</b>	<b>London &amp; SE</b>	<b>471418</b>	<b>4347</b>	<b>102</b>	<b>5741044</b>	<b>170953</b>	<b>3.0</b>	<b>5405976</b>	<b>6076112</b>
<b>all arable</b>	<b>North East</b>	<b>148676</b>	<b>1633</b>	<b>31</b>	<b>1272118</b>	<b>85890</b>	<b>6.8</b>	<b>1103773</b>	<b>1440462</b>
<b>all arable</b>	<b>North West</b>	<b>100998</b>	<b>2886</b>	<b>18</b>	<b>664732</b>	<b>76361</b>	<b>11.5</b>	<b>515065</b>	<b>814398</b>
<b>all arable</b>	<b>Northern Ireland</b>	<b>37499</b>	<b>2467</b>	<b>213</b>	<b>312644</b>	<b>9086</b>	<b>2.9</b>	<b>294836</b>	<b>330452</b>
<b>all arable</b>	<b>Scotland</b>	<b>494168</b>	<b>9373</b>	<b>278</b>	<b>4286591</b>	<b>106512</b>	<b>2.5</b>	<b>4077827</b>	<b>4495355</b>
<b>all arable</b>	<b>South West</b>	<b>407582</b>	<b>7594</b>	<b>84</b>	<b>4203726</b>	<b>161382</b>	<b>3.8</b>	<b>3887417</b>	<b>4520035</b>
<b>all arable</b>	<b>Wales</b>	<b>58526</b>	<b>2292</b>	<b>14</b>	<b>333717</b>	<b>30901</b>	<b>9.3</b>	<b>273151</b>	<b>394283</b>
<b>all arable</b>	<b>West Midlands</b>	<b>337384</b>	<b>5072</b>	<b>61</b>	<b>3443346</b>	<b>173515</b>	<b>5.0</b>	<b>3103256</b>	<b>3783436</b>
<b>all arable</b>	<b>Yorks. &amp; the Humber</b>	<b>491387</b>	<b>5382</b>	<b>92</b>	<b>5115949</b>	<b>156742</b>	<b>3.1</b>	<b>4808735</b>	<b>5423162</b>

Table 2: Estimates of mass applied by crop and region

Crop	Region	Total area	Number of holdings	Number of holdings surveyed	Estimate (Kg)	s.e (Kg)	RSE (%)	95% C.I. (Kg)	
sugar beet	East Midlands	19964	940	32	70010	3861	5.5	62442	77579
sugar beet	Eastern	53618	2123	65	209148	8955	4.3	191597	226698
sugar beet	Yorks. & the Humber	6407	466	4	15971	1729	10.8	12582	19360
potatoes ware	East Midlands	662	256	18	8828	885	10.0	7094	10562
potatoes ware	Eastern	4449	477	24	71129	5380	7.6	60584	81675
potatoes ware	London & SE	342	75	2	4166	369	8.8	3444	4888
potatoes ware	North East	100	27	2	658	400	60.8	NA	NA
potatoes ware	North West	759	264	2	11853	108	0.9	11641	12066
potatoes ware	Northern Ireland	3374	454	40	28797	1542	5.4	25775	31819
potatoes ware	Scotland	14766	1680	46	155024	8732	5.6	137908	172140
potatoes ware	South West	1462	273	6	17349	3336	19.2	10810	23888
potatoes ware	West Midlands	1493	284	9	24721	2456	9.9	19906	29535
potatoes ware	Yorks. & the Humber	936	288	11	13012	1381	10.6	10305	15719
oilseed rape	East Midlands	139411	2964	116	459392	15602	3.4	428813	489972
oilseed rape	Eastern	129945	3171	123	393179	13943	3.5	365852	420506
oilseed rape	London & SE	71462	1577	63	249145	11999	4.8	225627	272663
oilseed rape	North East	23506	735	22	52444	4505	8.6	43615	61273
oilseed rape	North West	4963	256	4	10341	2372	22.9	5692	14990
oilseed rape	Northern Ireland	552	45	13	1304	86	6.6	1135	1473
oilseed rape	Scotland	30141	1036	78	82902	5599	6.8	71929	93875
oilseed rape	South West	50134	1515	43	159259	9779	6.1	140093	178425
oilseed rape	Wales	5080	154	2	16964	4611	27.2	7925	26002
oilseed rape	West Midlands	49075	1716	41	109385	7805	7.1	94088	124683
oilseed rape	Yorks. & the Humber	74309	2431	71	197706	9408	4.8	179266	216147
winter barley	East Midlands	49331	1932	58	169171	10419	6.2	148749	189592
winter barley	Eastern	89775	2846	108	316391	14929	4.7	287129	345653
winter barley	London & SE	36415	1225	51	166034	10522	6.3	145410	186657
winter barley	North East	28748	1019	26	74546	7107	9.5	60616	88476
winter barley	North West	16383	1052	13	37099	5597	15.1	26129	48070
winter barley	Northern Ireland	7628	691	133	21675	768	3.5	20170	23179
winter barley	Scotland	48030	2009	96	164521	5008	3.0	154705	174337
winter barley	South West	48869	2607	48	172527	10926	6.3	151113	193942



winter barley	Wales	8131	657	8	14608	2057	14.1	10576	18640
winter barley	West Midlands	35087	1880	34	82431	6362	7.7	69962	94900
winter barley	Yorks. & the Humber	71044	2953	76	199549	11942	6.0	176142	222955
spring barley	East Midlands	60087	2161	74	117831	8445	7.2	101278	134384
spring barley	Eastern	89247	3079	98	150463	10005	6.6	130853	170072
spring barley	London & SE	66092	1672	53	174246	14651	8.4	145529	202963
spring barley	North East	12272	595	15	18934	3042	16.1	12971	24896
spring barley	North West	24073	1556	14	23918	4340	18.1	15410	32425
spring barley	Northern Ireland	14708	1608	162	26810	1045	3.9	24762	28858
spring barley	Scotland	238900	7154	240	408951	13129	3.2	383219	434683
spring barley	South West	85290	3957	56	153109	10574	6.9	132384	173833
spring barley	Wales	13758	1341	12	14079	2079	14.8	10004	18153
spring barley	West Midlands	28499	1718	13	33528	6050	18.0	21670	45387
spring barley	Yorks. & the Humber	50046	2507	47	76720	6969	9.1	63062	90379
wheat	East Midlands	335039	4822	139	1731127	59899	3.5	1613726	1848528
wheat	Eastern	467515	6250	187	2384258	63557	2.7	2259687	2508829
wheat	London & SE	218759	3308	102	1159916	42459	3.7	1076696	1243135
wheat	North East	67600	1290	29	259890	15647	6.0	229222	290557
wheat	North West	37315	1438	10	119578	22959	19.2	74577	164578
wheat	Northern Ireland	8616	659	119	26845	995	3.7	24896	28795
wheat	Scotland	109593	2846	171	484602	9995	2.1	465012	504192
wheat	South West	159035	4266	72	714957	35524	5.0	645329	784585
wheat	Wales	21411	623	8	52743	11613	22.0	29981	75505
wheat	West Midlands	163494	3723	60	606423	26352	4.3	554773	658073
wheat	Yorks. & the Humber	234960	4388	87	938041	37739	4.0	864072	1012010
<b>all arable</b>	<b>East Midlands</b>	<b>687630</b>	<b>5915</b>	<b>142</b>	<b>2928419</b>	<b>102992</b>	<b>3.5</b>	<b>2726554</b>	<b>3130283</b>
<b>all arable</b>	<b>Eastern</b>	<b>970309</b>	<b>7515</b>	<b>196</b>	<b>4212074</b>	<b>126521</b>	<b>3.0</b>	<b>3964093</b>	<b>4460055</b>
<b>all arable</b>	<b>London &amp; SE</b>	<b>471418</b>	<b>4347</b>	<b>102</b>	<b>2016527</b>	<b>68044</b>	<b>3.4</b>	<b>1883161</b>	<b>2149893</b>
<b>all arable</b>	<b>North East</b>	<b>148676</b>	<b>1633</b>	<b>31</b>	<b>417886</b>	<b>30985</b>	<b>7.4</b>	<b>357155</b>	<b>478616</b>
<b>all arable</b>	<b>North West</b>	<b>100998</b>	<b>2886</b>	<b>18</b>	<b>215613</b>	<b>41068</b>	<b>19.0</b>	<b>135121</b>	<b>296106</b>
<b>all arable</b>	<b>Northern Ireland</b>	<b>37499</b>	<b>2467</b>	<b>213</b>	<b>117654</b>	<b>5347</b>	<b>4.5</b>	<b>107175</b>	<b>128133</b>
<b>all arable</b>	<b>Scotland</b>	<b>494168</b>	<b>9373</b>	<b>278</b>	<b>1406510</b>	<b>47635</b>	<b>3.4</b>	<b>1313146</b>	<b>1499874</b>
<b>all arable</b>	<b>South West</b>	<b>407582</b>	<b>7594</b>	<b>84</b>	<b>1407629</b>	<b>70184</b>	<b>5.0</b>	<b>1270067</b>	<b>1545190</b>
<b>all arable</b>	<b>Wales</b>	<b>58526</b>	<b>2292</b>	<b>14</b>	<b>97990</b>	<b>12654</b>	<b>12.9</b>	<b>73188</b>	<b>122791</b>
<b>all arable</b>	<b>West Midlands</b>	<b>337384</b>	<b>5072</b>	<b>61</b>	<b>1188888</b>	<b>98641</b>	<b>8.3</b>	<b>995551</b>	<b>1382225</b>
<b>all arable</b>	<b>Yorks. &amp; the Humber</b>	<b>491387</b>	<b>5382</b>	<b>92</b>	<b>1672116</b>	<b>73112</b>	<b>4.4</b>	<b>1528816</b>	<b>1815416</b>

Table 3: Estimates of total area of application for each crop

Crop	Estimate (Ha)	s.e (Ha)	RSE(%)	95% C.I (Ha)	
sugar beet	864315	30007	3.5	805501	923129
potatoes ware	623652	14486	2.3	595259	652044
oilseed rape	5933246	86536	1.5	5763635	6102858
winter barley	4183572	57645	1.4	4070588	4296557
spring barley	4376862	61839	1.4	4255658	4498066
wheat	24209861	249752	1.0	23720347	24699376
<b>all arable</b>	<b>45309262</b>	<b>496800</b>	<b>1.1</b>	<b>44335535</b>	<b>46282989</b>

Table 4: Estimates of total mass applied for each crop

Crop	Estimate (Kg)	s.e (Kg)	RSE(%)	95% C.I (Kg)	
sugar beet	295129	9904	1.1	275718	314540
potatoes ware	335538	11302	1.8	313386	357691
oilseed rape	1732021	30089	0.5	1673046	1790996
winter barley	1418551	29264	0.7	1361195	1475908
spring barley	1198588	28088	0.6	1143536	1253640
wheat	8478378	117552	0.5	8247977	8708780
<b>all arable</b>	<b>15681304</b>	<b>237383</b>	<b>0.5</b>	<b>15216034</b>	<b>16146575</b>

i BIPM, (2008). Evaluation of measurement data — Guide to the expression of uncertainty in measurement, JCGM 100:2008

ii Isserlis, L. (1918). "On the value of a mean as calculated from a sample". Journal of the Royal Statistical Society. 81 (1): 75–81.