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An investigation of seed treatments for the control of crow damage to newly-sown wheat

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Seed treatments for the control of crow damage to seed and seedling in winter and spring wheat were evaluated in field trials from 2004 to 2007. Treatments included six fungicides, three insecticides, a product marketed as a bird repellent and three potential repellents. Various rates of selected compounds were investigated. Winter wheat was sown in December and spring wheat in late-January to mid-February. Sowing depth was 2 to 4 cm while some selected treatments were also sown at a depth of 5 to 8 cm. Crow damage was assessed by plant density and grain yield. Severe damage by crows was recorded. The plant population from untreated spring wheat seed in 2004, 2005 and 2006 was reduced by 59%, 69% and 89%, respectively. The corresponding reductions caused by crows to winter wheat sown in 2004, 2005 and 2006 were 96%, 88% and 96%. Best control of crow damage was provided by the fungicide Thiram. Increasing the rate of Thiram applied to seed reduced crow damage and increased plant density in the range 42 to 70% and 36 to 57%, respectively, for spring and winter wheat when compared with untreated seed. Anchor, which contains the fungicides Thiram and Carboxin, also gave reasonably good control. The commonly used fungicide product Panoctine gave poor control of crow damage. Other treatments investigated were ineffective in controlling damage. Increasing the sowing depth to more than 4.6 cm significantly reduced damage to both treated and untreated seed when compared with similar treatments sown less deep.

Keywords: crows; grain yield; plant population; seed treatment

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Introduction

Rooks (*Corvus frugilegus* L.), commonly known as crows, are widespread and numerous in Ireland throughout the year. Included in the diet of crows are insects, worms, snails, slugs, berries, legumes and cereals. The most serious crow damage to cereals is due to feeding on seed either before or after emergence resulting in a reduced plant population. Cereal crops sown in late autumn or early spring, which are mostly wheat, may be subjected to major damage by the feeding activity of crows with plant densities being reduced by more than 50% (Kennedy, unpublished). Control of crow damage to cereals is difficult and products such as Morkit (anthraquinone, 0.06%) which was marketed as a crow-repellent only provides limited control (Kennedy and Connery, 1994). Prior to 2002, the insecticide Kotol (lindane) was applied for the control of wireworm damage to all wheat, barley and oat seed sold in Ireland. This insecticide also provided some control of crow damage to germinating and establishing cereal crops. Investigations in the early 1990s (Kennedy, 2002) indicated that the seed fungicide Panoctine (active ingredient guazatine) was more effective than Kotol (active ingredient lindane) in preventing crow damage to cereals. The occurrence of relatively serious crow damage to some Panoctine-treated cereal crops in recent seasons has raised concerns about its continued effectiveness. The objective of this investigation was to evaluate various seed-applied treatments, including fungicides, insecticides and products considered to have bird repellent properties, for the control of crow damage to germinating and establishing wheat seedlings.

Materials and Methods

Seed treatments

The control of crow damage to newly-sown and establishing winter and spring wheat, by means of seed treatments, was investigated at Oak Park, Carlow, in the production seasons of 2004 to 2007. The seed treatments and rates of application included 6 fungicides, 3 insecticides, a product marketed as a bird repellent and three potential repellents. The set of treatments used varied with year and crop (Table 1). Products were selected either because of reputed or expected bird repellent effects. Treatments were applied to seed within one week before sowing. Application to seed was by means of a specialised applicator (Wintersteiger, Model HEGE 11).

Experimental design

The design of each trial was a randomised complete block with five replicates per treatment. The dimension of each plot replicate was 2 m × 20 m. Adjacent plots were separated by fallow strips 0.4 m wide and plot ends by strips 1 m wide. Sowing was by means of a Wintersteiger seeder (A-4910 Type PDS-14) at a rate of 179.3 kg/ha. The 1000 grain weight of seed was recorded for the purpose of estimating the potential plant population in the absence of crow damage. The germination capacity of seed was assumed to be 95%. Normal depth of sowing ranged from 2 to 4 cm. In 2005, untreated seed of spring wheat was sown at 4 cm and 8 cm and compared for crow damage. Selected treatments of winter wheat were sown at 4 cm and 8 cm deep in 2005/06. Similar treatments were applied to spring wheat and were sown at 2.8 cm and 4.7 cm in 2006. Spring wheat (cv Raffles) was sown on 27 January, 15 February and 9 February in 2004, 2005

Table 1. Products applied as seed treatments

Common name	Active ingredient(s)	Type	Product application rates (l/t)
Panoctine[†]	Guazatine (30)[1]	Fungicide	2
Anchor[†]	Carboxin + thiram (20+20)	Fungicide	3
Thiram[†2]	Thiram (50)	Fungicide	1, 2, 4 and 8
Beret-Gold[†]	Fludioxinil (2.5)	Fungicide	2
Robust[†]	Imazalil + triticonazole (1.1+1.1)	Fungicide	4
Kinto[†2]	Triticonazole + Prochloraz (6+2)	Fungicide	2
Evict[3]	Tefluthrin (10)	Insecticide	2
Cruiser[3]	Thiamethoxam (35)	Insecticide	1
Kotol[4]	Lindane (12.5)	Insecticide	1
Morkit[2]	Anthraquinone (25)	Bird-repellent	2.25[a]
Bitrex[5]	Denatonium benzoate (25)	Repellent	2[b]
Grape extract[3]	Methyl anthranilate (12.5)	Repellent	2
Grape extract[3]	Methyl anthranilate (25)	Repellent	2
Grape extract[5]	Methyl anthranilate (50)	Repellent	2, 4 and 8
Disco Agro[6]	Methyl anthranilate + other fruit extracts	Repellent	1.5, 3 and 6
Copper oxychloride[†3]	Copper oxychloride (50)	Repellent	11.5

[†] Registered for use in Ireland.
[a] kg/t.
[b] Solutions containing 0.02, 0.1, 0.25, 0.5, 1.25, 2.5, 10, 20, 40 and 80 g/l were each applied at a rate of 2 l/t of seed.
[1] Percent active ingredient(s).
[2] Not applied to spring wheat in 2004.
[3] Spring wheat in 2004 only.
[4] Applied to winter wheat for 2006 and 2007, spring wheat in 2006.
[5] Spring wheat in 2004 and 2005, winter wheat for 2005.
[6] Winter wheat for 2007 only.

and 2006, respectively. Winter wheat was sown on 3, 9 and 21 December in the same years; the varieties were Einstein, Glasgow and Cordiale. Normal husbandry practices were applied to both winter and spring wheat crops. Harvesting was by means of a specially modified combine harvester (Duetz-Fahr 3370; Modifications by Trials Equipment Ltd., Essex, UK).

Observations

The experimental sites were observed for the presence of crows for 10 weeks after sowing. Spring and winter wheat sites were visited 5 times per day and the number of crows present was recorded.

Assessments

Crow damage was assessed by recording plant population and grain yield. Plant populations were recorded at growth stage 22 to 23 (Tottman, Makepeace and Broad, 1979) by counting plants within a quadrat (0.5 m^2). The two outermost drills on each side of the 14-drill plot were omitted from plant counts due to more pronounced crow damage at the edges of plots. Quadrat counts were made at four positions, approximately 4 m apart, on a single diagonal of each plot. Plot yields were recorded at harvest. Grain moisture was measured in a hot-air oven. Yields were expressed at 85% dry matter.

Data analysis

The data were analysed using the general linear model procedures (SAS 9.1, 2003). Pair-wise differences between treatments were evaluated using Tukey's test. The mean plant density values for both winter and spring wheat seed sown at two depths were compared by means of a *t*-test. A *t*-test was also used to evaluate the impact of sowing depth for individual treatments. The impact of sowing depth on grain yields was determined by calculating standard error of difference values (s.e.d.). Correlation between plant density and grain yield was obtained using the mean values of treatments.

Results

Crows were numerous on the trial sites, particularly during the first three weeks post sowing. On spring wheat in 2004, up to 500 crows per visit were recorded during the 2 weeks post sowing. Thereafter there were fewer than 100 crows per visit. In 2005 and 2006 the number of crows never exceeded 60 per visit. In the case of winter wheat sown in December 2004 fewer than 20 crows/visit were recorded during the day. However, at dusk flocks ranging from 200 to 600 crows were recorded. In 2005 and 2006 the number of crows on the trial sites in the weeks post sowing ranged between 50 and 100. Most damage was due to feeding on seed before seedling emergence. In the days post sowing crow damage was evident by lines of holes corresponding to where seeds were located and excavated. Limited damage resulted from the uprooting of seedlings by crows. Damage to spring wheat in 2004 was concentrated on the most elevated area of the site. In the remaining trials damage was relatively even across replicates.

Spring wheat

Plant populations: Crow damage to spring wheat was severe in 2004, 2005 and 2006. Damage to untreated seed was 59%, 69% and 89%, respectively. Thiram, which was investigated in 2005 and 2006, gave the best control of crow damage (Table 2). Treating seed with this product at 1, 2, 4 or 8 l/t of seed resulted in significantly ($P < 0.05$) greater plant populations when compared with untreated seed. The highest plant population recorded for the treatments investigated in 2005 was for Thiram at 4 l/t while in 2006 this product at 8 l/t was best. Increasing the application rate of Thiram from 1 to 2 l/t of seed, in 2005, increased the plant population by almost 18%. However, there was no significant improvement in plant population from applying this product at 4 or 8 l/t. Increasing the rate of Thiram from 1 l/t of seed to 2, 4 and 8 l/t, in 2006, increased plant density by 41.8%, 120.3% and 131.2%, respectively. The plant densities for Thiram at 4 and 8 l/t were significantly ($P < 0.05$) greater than for this product applied at either 1 or 2 l/t. Anchor, applied at 3 l/t, increased the plant population compared with untreated seed in all three seasons. These increases were significant in 2005 and 2006 and were 104% and 195%, respectively, higher than for untreated seed. Anchor, which is a mixture of the fungicides Thiram and Carboxin, had rather similar plant populations to that for Thiram at 1 l/t. There was a modest, but not significant, increase in plant population in 2004 from applying Anchor at 6 l/t compared with the recommended rate of 3 l/t. The availability of Thiram in 2005 facilitated the investigation of various rates of this product without having to use increased rates of Anchor. Panoctine at the recommended rate (2 l/t) increased the plant population, though not significantly, by 18%, 60% and 70% relative to untreated seed in the 3 years. Panoctine,

Table 2. The effect of seed treatment on plant density (number per 1 m^2) for spring wheat

Treatment		Year		
Product	Application rate (l/t)	2004	2005	2006
Thiram	8	–	266.4^{a}	314.4^{a}
Thiram	4	–	273.2^{a}	299.6^{a}
Thiram	2	–	268.2^{a}	192.8^{b}
Thiram	1	–	227.8^{abc}	136.0^{bc}
Anchor	3	204.2^{a}	236.0^{ab}	126.4^{bc}
Anchor	6	215.8^{a}	–	–
Panoctine	2	180.6^{a}	185.4^{bcde}	72.6^{cd}
Panoctine	3	–	217.8^{abcd}	99.2^{cd}
Panoctine	4	155.4^{a}	–	–
Morkit	2.25[2]	–	172.4^{bcde}	83.2^{cd}
Beret-Gold	2	200.6^{a}	172.6^{bcde}	76.6^{cd}
Grape-extract 12.5%	2	190.4^{a}	–	–
Grape-extract 25%	2	195.0^{a}	–	–
Grape-extract 50%	2	180.8^{a}	134.2^{e}	–
Grape-extract 50%	4	–	150.2^{de}	–
Grape-extract 50%	8	–	153.2^{cde}	–
Bitrex 0.02[1]	2	176.0^{a}	–	–
Bitrex 0.1[1]	2	145.6^{a}	–	–
Bitrex 0.25[1]	2	121.2^{a}	–	–
Bitrex 0.5[1]	2	167.2^{a}	–	–
Bitrex 1.25[1]	2	173.6^{a}	–	–
Bitrex 2.5[1]	2	–	146.6^{de}	–
Bitrex 10[1]	2	–	156.0^{cde}	–
Bitrex 20[1]	2	–	142.0^{e}	–
Bitrex 40[1]	2	–	150.2^{de}	–
Bitrex 80[1]	2	–	134.4^{e}	–
Copper oxychloride	11.5	165.4^{a}	–	–
Robust	4	147.2^{a}	170.8^{bcde}	–
Kotol	1	–	–	67.6^{cd}
Cruiser	1	138.0^{a}	–	–
Evict	2	126.0^{a}	–	–
Kinto	2	–	168.0^{bcde}	84.6^{cd}
Untreated		153.0^{a}	115.6^{e}	42.8^{d}

[1] Active ingredient (g/l).
[2] kg/t.
[abcde] Means, within a column, without a superscript in common are significantly different ($P < 0.05$).

however, gave poor control of crow damage since seed treated with this product had only 48%, 50% and 19% of potential plant population in the three years. Increasing the rate of Panoctine applied to seed to twice the recommended rate, in 2004, resulted in lower plant density relative to that for a single treatment. There was a modest and non-significant increase in plant population from treating seed with Panoctine at 1.5 times the recommended rate. The bird repellent (Morkit) improved plant density relative to untreated seed by non-significant amounts. Morkit had significantly fewer plants than Thiram applied at either 2, 4 or 8 l/t in 2005 and 2006. Treating seed with the fungicides Beret-Gold and Kinto resulted in rather similar plant populations to that for Morkit. Grape extract showed only slight control of crow damage with plant populations not being significantly greater than untreated seed. Increasing both concentration and volume of Grape extract applied to seed failed to improve plant density. The number of wheat plants established from Bitrex-treated seed did not differ significantly from that for untreated seed in either 2004 or 2005. The ineffectiveness of Bitrex in controlling crow damage to newly-sown wheat in 2004 was confirmed in 2005 when higher rates of the product were applied to seed. The treatment of seed with Robust in 2005 and Kotol in 2006 did not indicate that these products could provide effective control of crow damage to newly-sown spring wheat.

Grain yield: The grain yield for spring wheat treatments are given in Table 3. The correlations between plant population and

Table 3. The effect of seed treatment on grain yield (t/ha; at 85% dry matter) for spring wheat

Treatment		Year		
Product	Application rate (l/t)	2004	2005	2006
Thiram	8	–	9.85[a]	7.97[ab]
Thiram	4	–	9.71[ab]	8.08[a]
Thiram	2	–	9.72[ab]	6.99[abc]
Thiram	1	–	9.71[ab]	6.33[cd]
Anchor	6	8.32[ab]	–	–
Anchor	3	8.85[ab]	9.73[ab]	6.49[bcd]
Panoctine	2	8.37[ab]	8.94[abcd]	5.58[cde]
Panoctine	3	–	8.99[abcd]	5.93[cde]
Panoctine	4	8.01[ab]	–	–
Morkit	2.25[2]	–	9.25[abc]	5.40[de]
Beret-Gold	2	8.77[ab]	8.68[abcd]	5.58[cde]
Grape-extract 12.5%	2	8.90[a]	–	–
Grape-extract 25%	2	7.53[ab]	–	–
Grape-extract 50%	2	7.72[ab]	8.38[cd]	–
Grape-extract 50%	4	–	8.76[abcd]	–
Grape-extract 50%	8	–	8.44[cd]	–
Bitrex 0.02[1]	2	7.70[ab]	–	–
Bitrex 0.1[1]	2	7.96[ab]	–	–
Bitrex 0.25[1]	2	6.34[b]	–	–
Bitrex 0.5[1]	2	7.51[ab]	–	–
Bitrex 1.25[1]	2	8.55[ab]	–	–
Bitrex 2.5[1]	2	–	8.31[cd]	–
Bitrex 10[1]	2	–	8.76[abcd]	–
Bitrex 20[1]	2	–	8.15[cd]	–
Bitrex 40[1]	2	–	8.51[bcd]	–
Bitrex 80[1]	2	–	8.01[d]	–
Copper oxychloride	11.5	8.86[ab]	–	–
Robust	4	7.64[ab]	8.60[bcd]	–
Kotol	1	–	–	5.50[cde]
Cruiser	1	7.63[ab]	–	–
Evict	2	7.25[ab]	–	–
Kinto	2	–	8.77[abcd]	5.32[de]
Untreated	–	6.99[ab]	8.09[cd]	4.79[e]

[1,2] See footnotes to Table 2.
[abcde] See footnotes to Table 2.

grain yield in 2004, 2005 and 2006 were 0.68, 0.92 and 0.98, respectively. The best yield for 2004 was 8.9 t/ha, recorded for the Grape-extract treatment at 12.5% concentration. The latter treatment differed significantly from only one other treatment, Bitrex 0.25 g/l. While yields differed substantially between some treatments, differences were not significant due to the non-random damage by crows. In 2005, Thiram, applied at 8 l/t, had the highest yield (9.85 t/ha). The yields for Thiram (at the four rates), Anchor and Morkit were significantly greater than that recorded for the untreated seed. The remaining treatments did not differ significantly from that for the untreated seed. Plots from seed treated with Bitrex 80 g/l active ingredient yielded less than the untreated seed plots. In 2006, two products, Thiram and Anchor, had significantly greater yields relative to that for untreated seed. Thiram applied at 4 l/t had the best yield (8.08 t/ha) which exceeded that for untreated seed by 3.29 t/ha. Thiram applied at 4 and 8 l/t of seed had significantly greater yield than Panoctine (at either the recommended rate or at 1.5 times this rate), Morkit, Beret-Gold, Kinto and Kotol. The latter treatments out yielded that for untreated seed by non-significant amounts varying from 0.53 to 1.14 t/ha.

Winter wheat

Plant populations: The plant populations for the various treatments applied to winter wheat seed for the three seasons 2005 to 2007 are given in Table 4. Feeding on winter wheat seed by crows was extensive and damage was severe. The damage to untreated seed, due to crows, in 2005 and 2007 was 96% while in 2006 it was 88%. While Thiram had more plants relative to other treatments in each of the three seasons, however, when the attack by crows was severe as in 2004/2005 Thiram even when applied at 8 l/t had only 26.6 plants/m^2. As with spring wheat, increasing the rate of Thiram from 1 to 2, 4 and 8 l/t of seed resulted in increased plant density. Seed treated at 8 l/t in 2006 and 2007 had significantly more plants when compared with this product applied at 1 l/t or 2 l/t. While Thiram at 8 l/t gave the best control of crow damage, this treatment had only 7%, 68% and 40% of the potential plant population in the three seasons. Because the damage was so severe in 2005 and 2007 the trials were terminated by ploughing up in late spring. The plant population in 2006, of 68% recorded for the high rate of Thiram corresponded to 245 plants/m^2 which had the potential to produce an acceptable grain yield. The plant population resulting from treating seed with Thiram at 4 l/t, was 75% that from applying Thiram at 8 l/t. In 2006, wheat plots grown from seed treated with Anchor and Panoctine treated seed, had 112.6 and 75.4 plants/m^2, respectively. These values did not differ significantly from that for untreated seed. The remaining treatments (Morkit, Panoctine (3 l/t), Beret-Gold, Kinto and Kotol) gave poor control of crow damage with plant density reduced by more than 79%.

Grain yield: Data were obtained in 2006 only. There was a good relationship between plant density for the various treatments and grain yield (correlation coefficient 0.92). The highest yield was obtained for Thiram applied at 8 l/t (9.22 t/ha). The untreated seed yielded 5.3 t/ha. Thiram, applied at 1, 2, 4 and 8 l/t, and Anchor were the only treatments to have significantly greater grain yield relative to untreated seed. The respective increases in grain yield were 2.51, 2.79, 3.43, 3.92 and 2.75 t/ha. The remaining six treatments improved yield by non-significant amounts in the range 0.07 to 1.79 t/ha.

Table 4. The effect of seed treatments on plant density (number per 1 m^2) for winter wheat

Treatment		Year		
Product	Application rate (l/t)	2004/05	2005/06	2006/07
Thiram	8	26.6[a]	245.0[a]	156.6[a]
Thiram	4	18.2[ab]	193.6[ab]	–
Thiram	2	13.8[ab]	129.0[bc]	43.2[b]
Thiram	1	13.8[ab]	126.0[bc]	35.8[b]
Anchor	3	8.2[b]	112.6[bcd]	29.0[b]
Panoctine	2	15.4[ab]	75.4[cd]	27.4[b]
Panoctine	3	7.8[b]	51.4[cd]	–
Morkit	2.25[2]	8.8[b]	72.4[cd]	29.4[b]
Beret-Gold	2	7.4[b]	47.8[cd]	–
Grape-extract 50%	2	14.2[ab]	–	–
Grape-extract 50%	4	5.0[b]	–	–
Grape-extract 50%	8	12.8[ab]	–	–
Disco Agro (fruit-extract)	6	–	–	19.4[b]
Bitrex 2.5[1]	2	11.4[ab]	–	–
Bitrex 10[1]	2	8.0[b]	–	–
Bitrex 20[1]	2	6.0[b]	–	–
Bitrex 40[1]	2	6.2[b]	–	–
Bitrex 80[1]	2	5.4[b]	–	–
Robust	4	11.6[ab]	–	–
Kotol	1	–	37.6[d]	16.0[b]
Kinto	2	12.4[ab]	41.8[d]	–
Untreated	–	13.0[ab]	42.2[d]	14.6[b]

[1,2] See footnotes to Table 2.
[abcd] See footnotes to Table 2.

Sowing depth

Increasing the sowing depth of untreated spring wheat seed from 4 cm to 8 cm, in 2005, resulted in a significant ($P < 0.05$) reduction in damage by crows. The respective plant densities were 115.6 and 218.4 plants/m^2. The grain yield for the seed sown at 8 cm was greater, by 0.84 t/ha, than for seed sown at 4 cm but this difference was not significant. In 2006, the overall level of crow damage to winter wheat seed treated with Thiram (2 l/t), Anchor, Panoctine, Kotol, Kinto, Beret-Gold or untreated sown at 4 cm was significantly greater when compared with the overall level when the treatments were sown at 8cm (Table 5). Additionally, plant density for each treatment was significantly greater at 8 cm than at 4 cm. The increases ranged from 2 to 5.3 fold. Four of the six treatments and the untreated seed had significantly ($P < 0.01$) greater grain yield when sown at 8 cm compared with 4 cm. Overall, the mean yield for treatments and untreated seed sown at 8 cm was greater by 2.1 t/ha (range 0.77 to 3.44 t/ha) than when sown at 4 cm. The extent of crow damage to spring wheat sown at 2.8 cm or 4.7 cm in 2006, showed a similar trend to that obtained for the same treatments applied to winter wheat seed sown in 2005. Collectively, treated and untreated seed had significantly greater plant density and grain yield (Table 5) when sown at 4.7 cm compared with seed sown at 2.8 cm. Two seed treatments and the untreated seed had significantly more plants when sown at 4.7 cm compared with seed sown at 2.8

Table 5. Mean values for plant density (number per 1 m^2) and grain yield (t/ha) at 85% dry matter for each seed treatment when seeds were sown at different depths

Treatment		Sowing depth		Significance	Sowing depth		Significance
Product	Application rate (l/t)	4/2.8†	8/4.7†		4/2.8	8/4.7	
				Winter wheat (2005/2006)			
		Plant density			Grain yield		
Thiram	2	129.0^{a}	265.0^{a}	**	8.09^{a}	8.86^{a}	
Anchor	3	112.6^{ab}	274.4^{a}	**	8.05^{a}	8.98^{a}	**
Panoctine	2	75.4^{abc}	214.6^{ab}	**	7.09^{ab}	8.12^{a}	
Kotol	1	37.6^{c}	200.4^{ab}	*	5.37^{b}	8.32^{a}	**
Kinto	2	41.8^{bc}	189.8^{ab}	**	6.23^{ab}	8.75^{a}	**
Beret-Gold	2	47.8^{bc}	172.4^{b}	***	5.38^{b}	8.82^{a}	***
Untreated	–	42.2^{bc}	140.8^{b}	*	5.30^{b}	8.45^{a}	**
	Overall effect of sowing depth			***			
				Spring wheat (2006)			
		Plant density			Grain yield		
Thiram	2	192.8^{a}	236.2^{a}		6.99^{a}	7.07^{a}	
Anchor	3	126.4^{b}	210.0^{ab}		6.49^{ab}	6.93^{a}	
Panoctine	2	72.6^{bc}	176.6^{abc}	*	5.58^{abc}	6.69^{a}	*
Kotol	1	67.6^{bc}	161.8^{abc}		5.50^{abc}	6.05^{a}	
Kinto	2	84.6^{bc}	146.0^{bcd}	**	5.32^{bc}	6.32^{a}	
Beret-Gold	2	76.6^{bc}	132.8^{cd}		5.58^{abc}	6.56^{a}	
Untreated	–	42.8^{c}	85.4^{d}	*	4.79^{c}	6.01^{a}	**
	Overall effect of sowing depth			**			

† The first number is for winter wheat and the second number is for spring wheat.

^{abcd} Means, within a column for a given crop, without a common superscript are significantly different ($P < 0.05$).

cm, while one treatment and the untreated seed had significantly greater yield for the deeper sown seed (Table 5). The respective increases in plant density and grain yield for the deep sown seed were 170% (range 120 to 240%) and 113% (range 101 to 125%).

Discussion

The damage to spring and winter wheat due to crows feeding on seed and to a lesser extent uprooting seedlings, in trials, was more severe than anticipated. During each year the plant density in plots grown from untreated seed of spring and winter wheat were reduced by at least 59% and 88%, respectively. It would appear from the pattern of 'excavation' holes where damage occurs that crows are quite efficient at locating seed in newly-sown crops. In newly-emerged crops crows easily locate and uproot seedlings to feed on the remaining endosperm of the seed. With the exception of spring wheat in 2004, crow damage was random across the sites. In 2004 damage was greater on the most elevated section of the site possibly due to more easily accessible seed resulting from shallower planting. Apart from the spring wheat trial in 2004, when there were up to 500 crows/visit, fewer than 100 crows were recorded per visit during the hours of daylight. It was concluded that most damage was due to the feeding activity of those crows frequenting the sites during the day. However, the occurrence of large numbers of crows on trial sites at dusk, when flocks were congregating prior to their nightly return to nearby rookeries, may also be responsible for crop damage. Normally crow damage is associated with crops sown when food is scarce; for example, late-sown winter crops and early-sown spring crops. Damage is generally confined to individual crops and is seldom widespread across farms. While house crows (*Corvus splendens*) have been reported to damage seedling wheat in India (Dhindsa and Saini, 1994) bird damage to other seedling crops mostly concern rice (Bruggers *et al.,* 1981; Avery *et al.,* 1998, 2000; Cummings *et al.,* 2002). Most of the literature on bird damage to crops relates to ripening grain and fruit and involves various bird species other than crows (Stickley and Guarino, 1972; Kassa and Jackson, 1979; Duncan and Boswell, 1981; Mason and Clark, 1995; Blackwell, Helon and Dolbeer, 2001; Rizvi, Pervez and Ahmed, 2002).

In this study, Panoctine, which is the most widely used seed fungicide, gave poor control of crow damage. The plant density arising from seed treated with Panoctine was greater than that for untreated seed in all eight comparisons but only in one comparison was the difference significant. Increasing the rate of Panoctine applied to seed by a factor of two, in the hope of increasing crow repellency, caused phytotoxicity. The latter was confirmed in separate glasshouse studies. In three comparisons in the early 1990s seed treated with Panoctine yielded a significantly greater plant density than untreated seed (Kennedy, 2002). The reduced effectiveness of Panoctine in the current investigation is attributed to a more severe attack by crows as indicated by the level of damage to untreated seed. Winter wheat trials in the early 1990s were sown in early to mid November while in the current trials wheat was sown in December when few if any other crops were sown in the vicinity and food was likely to be less plentiful than in November. Anchor, which is the second most widely used fungicide for seed treatment of seed, had greater plant density than Panoctine in seven of the eight comparisons undertaken. Overall, Anchor had almost 27% more plants than Panoctine (range 6 to 74%). The crow repellent properties of Anchor are attributed to the Thiram element of the product. The bird repellency of Thiram was recorded by Parodi and Raczynski (1971) who found that applying sprays of Thiram to the ears of wheat at the milky-ripe stage of growth, in Chile, helped control bird damage and reduce yield loss. The use of Thiram as a seed treatment in India was found to give considerable protection to sprouting wheat from damage by house crows (Dhindsa and Saini, 1994). In France, the repellent effect of Thiram when applied to maize seed left in piles in the vicinity of rookeries was recorded by Grolleau and Jackson (2001). Based on the repulsive properties of Thiram, as measured by these workers in the laboratory, Thiram was registered as a bird repellent for maize and wheat in France in 1999. In the investigations reported here, Thiram, applied at 2 l/t of seed, increased plant density when compared with untreated seed and the increases were significant for four of the seven comparisons made. Increasing the rate of Thiram improved the control of crow damage. Overall, Thiram applied at 2, 4 and 8 l/t of spring and winter wheat seed resulted in 20%, 82% and 87% greater plant density, respectively, when compared with Thiram at 1 l/t. The corresponding increases in grain yields were 4%, 11% and 13%, respectively. In the trials in which Thiram gave good control of crow damage the 4 l/t rate was as effective as the 8 l/t rate in the case of spring wheat and was 75% as effective for winter wheat. It would seem reasonable, therefore, to expect that enhanced control of crow damage to wheat could be achieved by increasing the Thiram element of the product Anchor, which is a registered pesticide in Ireland.

Morkit, which was marketed as a bird repellent was investigated in four trials, did provide some protection against damage by crows, however, neither plant density nor grain yield were significantly greater when compared with untreated seed. In laboratory/aviary trials anthraquinone (Morkit) has been found to deter sand-cranes from feeding on treated maize kernels (Blackwell *et al*., 2001) and red-winged-blackbirds and brown-headed cowbirds from feeding on treated rice seed (Avery *et al.,* 1998; Cummings *et al.,* 2002). However, while some control of bird damage to seedling rice and grassland by anthraquinone in field studies has been reported (Avery *et al.,* 1998; Cummings *et al.,* 2002; Dolbeer *et al.,* 1998) the control of crow damage in field trials, as recorded in the present study, was modest. It should be noted that the recommended rate for applying anthraquinone to wheat seed is 0.06% whereas in the above studies with maize and rice it was applied at either 0.5% or 1%. Kotol, prior to its removal from use in 2001, was considered to control crow damage to cereals. However, investigations in the early 1990s (Kennedy, 2002) showed that while Kotol treated seed always produced more plants than untreated seed the differences were not always significant. The treatment of winter wheat seed (in 2004 and 2005) and spring wheat (in 2006) with Kotol obtained in 1994 showed the product produced only marginally and non-significantly more plants than untreated seed. The reduced effectiveness of Kotol in controlling crow damage in these trials relative to earlier investigations was due in part to a more severe attack by crows but may also be attributable to diminished effectiveness due to the age of the product. Grape extract did give modest though non-significant increases in plant density relative to that for untreated seed. Nevertheless, even using this product at 50% concentration and increasing the rate of application by 4-fold failed to control crow damage. The Disco Agro product (fruit extracts), was used on winter wheat sown in December 2006, also failed to control crow damage. Methyl anthranilate is registered as an avian feeding repellent (Avery, 2002) and is marketed in the U.S. mainly for use on fruit crops. In laboratory and aviary trials reduced feeding by various bird species has been recorded for bait and seeds treated with methyl anthranilate when compared with untreated controls (Mason, Clark and Miller, 1993; Clark, Bryant and Mezine, 2000; Blackwell *et al*., 2001). When used on ripening crops of rice and sunflowers, however, methyl anthranilate was ineffective in controlling damage by blackbirds (Werner *et al.,* 2005). At the commencement of the present study it was surmised that crows might be averse to feeding on seed treated with Bitrex (Denatonium benzoate) since the product is extremely bitter. However, treating seed wheat with Bitrex failed to deter crows from feeding on seed. This product was also ineffective in controlling pest damage to conifer seedlings in field trials in the U.S. (Witmer, Pipas and Bucher, 1998).

Increasing the depth of sowing significantly reduced the depletion of plant populations by crows. Sowing wheat at a depth of 5 cm should make seed unavailable to crows and the 'mother-seed' attached to seedlings emerging from this depth would be exhausted as a food source for crows and would therefore not be uprooted. However, sowing cereals at greater than this depth in heavy clay soils may result in problems with seedling emergence.

It is concluded that: (i) wheat crops sown in the period December to February are likely to be attacked by crows, particularly isolated crops in the vicinity of rookeries, (ii) where crops are under severe and prolonged attack by crows there is currently no seed treatment available that will give effective control, (iii) Thiram is the most effective of the seed treatments investigated for the control of crow damage to newly-sown and emerging cereal crops and should be applied at 4 l/t of seed, (iv) of the two seed treatments commercially available Anchor is more effective than Panoctine at reducing crow damage to newly sown wheat, (v) better control of crow damage to wheat crops could be obtained by increasing the Thiram element of Anchor and sowing seed at a depth of 5 cm in months other than December or January.

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