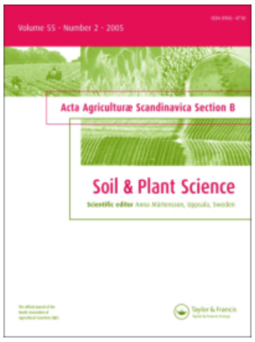

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Evaluation of pre-harvest desiccation strategies in red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) seed crops

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ABSTRACT
Desiccation with diquat about one week before seed harvest has been common practise in Norwegian clover seed production. However, after withdrawal of diquat in 2020, clover seed growers no longer have desiccators available. In 2019 and 2020, six field trials in red clover and two field trials in white clover were carried out to evaluate alternative chemical products at different rates and at two different spraying dates, either early at 50% mature seed heads and / or late at 65% mature seed heads. Products included, either for one or two years, was Spotlight Plus (carfentrazonethyl), Beloukha (pelargonic acid), Glypper (glyphosate), Gozai (Pyraflufen-ethyl), Harmonix LeafActive (acetic acid), Harmonix FoliaPlus (pelargonic acid), Flurostar (fluroxypyr) and Saltex (sodium chloride) and liquid urea-based fertilizers. In addition, swathing was examined as an alternative in two red clover trials in 2020. While none of the tested chemicals were superior to diquat, the most promising alternatives were Harmonix FoliaPlus and Harmonix LeafActive in red clover or Harmonix FoliaPlus in white clover. Although usually less effective than these products, Beloukha also had an acceptable desiccation effect, especially when sprayed early and late. Swathing before harvest, using finger bar cutters, was an effective drying method under favourable weather conditions.

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Chemical desiccation; lodging; seed harvest; seed yield; swathing

Introduction

In conventional Norwegian red clover (*Trifolium pratense* L.) seed production, it has been recommended to desiccate with diquat when about 50-60% of the flower heads are mature, usually in late August or early September, followed by threshing about one week later (Havstad & Susort, 2012). A similar practise has also been standard in the Norwegian white clover (*Trifolium repens* L.) seed production, though with an earlier harvesting date (normally in late July or early August) (Øverland, 2011). However, the long-lasting approval of diquat (introduced in Norway in 1964) was withdrawn on 4 February 2020, both in Norway and in the EU. The withdrawal was due to concerns that people and birds could be exposed to this highly toxic compound (European commission. 2018).

Chemical desiccation lowers the plant moisture which facilitates seed harvest and reduces seed loss. Harvesting experiments showed seed losses in red clover to be especially severe when moist plants were combined at a high driving speed (Aamlid & Øverland, 2018). Thus, for clover seed growers to be able to maximize seed yield, the use of desiccation products is of utmost importance. Consequently, after the withdrawal of diquat, the clover seed industry has been looking for alternatives. In a Canadian study (Kirk et al., 2017), glyphosate and saflufenacil (the latter not approved in Norway), either alone or in combination, did not reduce the plant moisture in red clover seed crops as much as diquat. However, several other desiccants or herbicides are now available on the international market, such as Spotlight Plus (active substance: carfentrazonethyl), Beloukha (active substance: pelargonic acid), Gozai (active substance: pyraflufen-ethyl), Harmonix LeafActive (active substance: acetic acid), Harmonix FoliaPlus (active substance: pelargonic acid), Flurostar (active substance: fluroxypyr) and Saltex (active substance: sodium chloride). For the seed growers, it would be highly beneficial if one or more of these products could be suitable and approved as a substitute for diquat.

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Like diquat (Sutten & Foy, 1971), most of the available contact herbicides, such as carfentrazonethyl (Thompson and Nissen, 2000), pyraflufen-ethyl (APVMA 2007), acetic acid (Webber et al., 2018) and pelargonic acid (Fukuda et al., 2004), act by destroying cell membranes in a light-dependent reaction, thus causing rapid desiccation of plant tissues. A similar membrane rupture, but by creating a strong osmotic gradient, occur in plants treated with sodium chloride (Brosnan et al., 2009). Of the systemic herbicides, fluroxypyr affect the hormone (auxin) balance (Guo et al., 2019), while glyphosate act by disrupting enzyme production in the shikimic acid pathway, thus causing reduction in the biosynthesis of aromatic amino acid (Rubin et al., 1982).

In addition to the chemical desiccators, it is a practical experience that foliar fertilizers may cause browning and death of leaves, especially if applied on wet plants in strong sunlight and/or and at high temperature (Dæhli, 2015). However, no information is available on whether liquid fertilizers (e.g. urea) may be useful as desiccants in clover seed production.

Swathing is another alternative to dry the clover crop before seed harvest. However, because of the low height of white clover seed crops and because red clover seed crops are normally lodged, the swathing height usually has to be less than 10 cm, thus leaving the windrows in close contact with the soil. This usually delays drying, especially if the windrows are thick and compact (Havstad & Susort, 2012). While the method is widely used in other European countries (Boelt, 2002), many Norwegian seed growers consider swathing to be an uncertain method because of unstable weather conditions during seed harvest. A focus on more open and less compact windrows could nevertheless be useful to reduce the time needed from swathing to seed harvest.

The objective of this study was to find alternative desiccators to diquat in white and red clover seed crops. In red clover, an additional aim was to examine if an improved swathing technique could be an alternative strategy to dry down the crop before seed harvest. Our hypothesis was that swathing and/or desiccation with one or several of the tested chemicals would be an adequate substitution for diquat in clover seed production.

Materials and methods

Experimental series I. Chemical desiccators in red clover seed crops, 2019

In 2019, desiccation products were compared in three red clover field trials at NIBIO Landvik Research Centre, Grimstad (58°20′ N, 8°31′E) (cv. Gandalf) and on seed growers' farms in Sandefjord (59°22′ N, 10°07′E) (cv. Gandalf) and Våler (59°29′ N, 10°54′E) (cv. Yngve), Norway. The products were applied at recommended rates, some of them on two different dates (Table 1), to plots that had a gross size of 3.0 m x 8.0 m and were completely randomized within each of three blocks.

Three extra experimental treatments were tested in Sandefjord only. Two of these were liquid Flex fertilizer sprayed out in equal amounts on both application dates (A and B), either 250 L ha^{-1} Flex Urea N18 (input of 45 kg N ha^{-1}) + 0.5 L ha^{-1} Renol vegetable oil (T 11) or 250 L ha^{-1} Flex Urea N24 fertilizer (input of 60.0 kg N ha^{-1}) + 0.5 L ha^{-1} Renol oil (T 12). The last treatment (13) was vinegar (acetic acid) in a concentration of

Table 1. Experimental treatments, including rates of products (L ha^{-1}) and active ingredients (kg ha^{-1}), applied on two dates (A and B) to red clover seed crops in 2019 (Experimental series I).

		Product application rate (L ha^{-1}) / Active ingredient rate (kg ha^{-1})	
Treatments (T)		10^{-1}4 days before seed harvest (ca 50 % of seed heads matured). Application date A	5-7 days before seed harvest (ca 65% of seed heads matured). Application date B
1	Spotlight Plus (60 g L^{-1} carfentrazone-ethyl) (no adjuvant)	-	1.0 / 0.06
2	Spotlight Plus + DP[a]	0.5 / 0.03	0.5 / 0.03
3	Beloukha (680 g L^{-1} pelargonic acid) (no adjuvant)	-	16.0 / 10.88
4	Beloukha (no adjuvant)	16.0 / 10.88	16.0 / 10.88
5	Gozai (26.5 g L^{-1} pyraflufen-ethyl) + Renol[b]	-	0.8 / 0.02
6	Gozai + Renol[b]	0.8 / 0.02	0.8 / 0.02
7	MCPA 750 (750 g L^{-1} MCPA) + Glypper (360 g L^{-1} glyphosate) (no adjuvant)	2.0 / 1.50 + 2.0 / 0.72	-
8	Beloukha + Spotlight (no adjuvant)	-	16.0 / 10.88 + 1.0 / 0.06
9	Glypper (early) + Beloukha (late) (no adjuvant)	2.0 / 0.72	16.0 / 10.88
10	Urea (46% N, liquid) (no adjuvant)	-	403
14	Reglone (200 g L^{-1} diquat) + DP[a] (control)	-	2.5 / 0.50
15	No desiccation (unsprayed control)	-	-

[a]0.05 l ha^{-1} DP adjuvant (900 g L^{-1} alcohol ethoxylate). b1.5 l ha^{-1} Renol (925 g L^{-1} vegetable oil). 3Urea: 40 kg N ha^{-1}.

8.75%, sprayed out in 500 L ha^{-1} (43.8 kg ha^{-1} a.i) on both dates and without any adjuvant.

Detailed information about the three trials, including weather conditions during the experimental period, are given in Table 2. All products were sprayed with a portable sprayer, driven by compressed air, at a pressure of 150 - 200 kPa and a spraying width of 2.5 m. Except for the liquid Flex treatments (11 and 12) at Sandefjord, the carrier volume was 500 L ha^{-1} water in all treatments.

Due to a fungal disease attack in the Landvik trial, the clover leaves were naturally withered before the first application date. This contrasted with the trials at Sandefjord and Våler where leaves were still green when sprayed. Due to the lack of intact foliage at Landvik, the seed crop colour was assessed in Sandefjord and Våler only. This was done visually according to a 1–9 scale, where 1 corresponded to clover plants with a fresh natural green colour on leaves and stems, 5 was a pale green colour (clearly visible sign of withering), and 9 was completely withered plants with a brown colour. The colour ranking of all treatments was performed by the same person in each trial.

At Landvik and Våler, per cent dry matter of intact clover plants (ca. 1 kg fresh weight), cut 5 cm above soil level, was determined on all plots soon before seed harvest. Per cent dry matter was determined after two days' drying at 60 °C. At Landvik, the determination only included stems since there were no leaves left.

The trial at Landvik was harvested with a conventional Dronningborg D3000 combine harvester (header width 2.8 m), with seeds being collected at the bottom of the combiner (before being transported to the seed tank). A Wintersteiger plot combine harvester (header width 1.5 m) was used in the trials at Sandefjord and Våler. While the cleaning sieve in the plot combiners were removed at Sandefjord and Våler, the top and bottom sieve on the conventional combiner used at Landvik were adjusted to 10 and 5 mm, respectively. Harvest plots were either 1.5 m x 6.5 m (Sandefjord and Våler) or 2.5 m x 6.5 m (Landvik). In all trials, stubble height at combining was 5–10 cm, and combiners were adjusted to a drum periphery speed of 26–27 m/s and a concave clearance of 6–7 mm in the front and 2–4 mm in the rear.

At Sandefjord, the water content of the uncleaned seed mass was determined by weighing the harvested seed bags shortly after combining and again after being dried down to stable storage conditions (about 12% seed water) by an unheated air dryer.

After drying, the plot yields from all trials were cleaned on a laboratory air-screen machine (LA-LS Air Screen Cleaner, Westrup AS, Denmark) at NIBIO Landvik. After cleaning, one pooled sample from each treatment in each trial was analysed for purity, thousand seed weight and germination according to international rules (ISTA 2019) in the seed laboratory at NIBIO Landvik.

Table 2. Dates for desiccation, determination of per cent dry matter in plant mass, colour assessment and seed harvest, as well as temperature and precipitation during the harvest period in three red clover trials in 2019 (Experimental series I).

	Landvik	Sandefjord	Våler
Date for the early desiccation (Application date A)	21 Aug.	2 Sep.	27 Aug.
Date for the late desiccation (Application date B)	27 Aug.	9 Sep.	2 Sep.
Determination of dry matter (%) in plant mass	5 Sep.	Not recorded	16 Sep.
Date for colour assessment and seed harvest	16 Sep.	20 Sep.	16 Sep.
Mean temperature (°C) / Precipitation (mm) from the first application date (A) to seed harvest[a]	14.7 / 118	11.9 / 63	13.9 / 144
Mean temperature (°C) / Precipitation (mm) from the second application date (B) to seed harvest1	14.2 / 92	12.1 / 16	12.5 / 115
Seed yield (averaged across treatments), kg ha^{-1}	270	415	826

[a]Meteorological data from the weather stations located closest to the trials at Landvik, Sandefjord and Våler. Distance from the trials were 0.5, 6 and 14 km, respectively.

Experimental series II. Swathing and chemical desiccators in red clover seed crops, 2020

The evaluation continued in 2020 with three new trials, all laid out according to a randomized complete block design with three blocks, in red clover cv. Gandalf. The experimental sites were NIBIO Landvik, Våler (same locations as in 2019) and Svarstad (59°39′ N, 09° 97′E). All products were tested at all locations except Harmonix FoliaPlus (T 3) which was evaluated at Landvik and Svarstad only. The application volume varied from 250 to 1000 L ha^{-1} according to recommendations for the various products (Table 3). Gross plot size and spraying procedures were as described for Experimental series I.

Swathing 5–7 days before seed harvest was included as an additional treatment (T 14) at two sites by using a motorized hedge trimmer (Stihl HS 45, Andreas Stihl AG, Germany) at Svarstad and a tractor-mounted finger bar swather (Tive SVA, AB Skurup-Verken, Sweden) at Landvik. The swathing height was 5 cm and the swathed plot size 1.5 m x 6.5 m at both sites.

Detailed information about the three trials, including weather conditions during the experimental period, can be found in Table 4. To keep the foliage healthy and green until desiccation/swathing, fungi were controlled with prothiokonazole,175 g ha^{-1} and trifloxystrobin,

Table 3. Experimental plan, including product rates (L ha^{-1}), active ingredients (kg ha^{-1}) and application volumes at two dates (A and B) to red clover (Experimental series II) and white clover (Experimental series III) seed crops in 2020.

Treatments (T)	Product application rate (L ha^{-1}) / active ingredient rate (kg ha^{-1})		
	10-14 days before seed harvest (ca 50 % of seed heads mature) Application date A	5-7 days before seed harvest (ca 65 % of seed heads mature) Application date B	Application volume (L ha^{-1} (Date A + B)
1 Spotlight Plus (60 g L^{-1} carfentrazone-ethyl) Mero oil[a]	1.0 / 0.06		300+0
2 Harmonix Leaf Active (240 g/L acetic acid) (no adjuvant)	250.0 / 60.00 12.0 /30.00	250.0 / 60.00 12.0 / 30.00	1000 + 1000
3 Harmonix FoliaPlus (250 g L^{-1} pelargonic acid) (no adjuvant)			
4 Beloukha (680 g L^{-1} pelargonic acid) (no adjuvant)	-	16.0 / 10.88	500 + 500 0 + 250
5 Beloukha (no adjuvant)	16.0 / 10.88	16.0 / 10.88	250 + 250
6 Vinegar (8,75% acetic acid) + DP[b]	50.0 / 43.75	50.0 /43.75	500 + 500
7 Vinegar (8,75% acetic acid) + DP[b]	-	50.0 /43.75	0 + 500
8 Glypper (360 g L^{-1} glyphosate) (no adjuvant)	2.0 / 0.72	-	250 + 0
9 Spotlight (+ Mero oil1) + Beloukha (no adjuvant)	1.0 / 0.06	16.0 / 10.88	300 + 250
10 Glypper (glyphosate) + Beloukha (no adjuvant)	2.0 / 0.72	16.0 / 10.88	250 + 250
11 Flurostar 200 (200 g L^{-1} fluroksypyr) (no adjuvant)	2.0 / 0.40	-	250 + 0
12 Saltex (22.5 % NaCl) +Mero oil[a]	800.0 / 214.00[d]	800.0 / 214.00[d]	800 + 800
13 Saltex (22.5 % NaCl) +Mero oil[a]	-	800.0 /214.00[d]	0 + 800
14 Swathing 5-7 days before seed harvest[c]	-	-	-
15 No desiccation or swathing (control)	-	-	-

[a]5 L ha^{-1} Mero oil (803 g L^{-1} vegetable oil). [b]0.5 L ha^{-1} DP adjuvant (900 g L^{-1} alcohol ethoxylate). [c]Swathing included in red clover only (Experimental series II). [d]Calculation based on a specific gravity of NaCl of 1.19 kg L^{-1}.

150 g ha^{-1}, (Delaro, SC 325, 1.0 L ha^{-1}, Bayer Crop Science, Leverkusen, Germany) in late July (Landvik) or early August (Svarstad and Våler) (Table 4).

As in 2019, seed harvest was carried out with a Dronningborg D3000 at Landvik and with Wintersteiger plot combiners at Svarstad and Våler. All combiners were adjusted to a drum periphery speed of 28–34 m/s and a concave clearance of 5–7 mm in the front and 3–4 mm in the rear. The plot combiners at Svarstad and Våler had no sieves, while both the top and the bottom sieves of the conventional combiner at Landvik were adjusted to 10 mm. The harvest plots were 1.5 m x 6.5 m at Svarstad and Våler and, with the exception of swathed plots, 2.5 m x 6.5 m at Landvik. Stubble height at combining varied from 5 cm (Landvik and Svarstad) to 12 cm (Våler).

Registrations included seed crop colour 0–4 days before seed harvest (Table 4) and water content in the uncleaned seed as earlier explained for Experimental series I. Unlike in Experimental series I, per cent dry matter was not determined in the intact crop before harvest, but in the straw after combining (drying of a ca 1 kg sample for two days at 60°C).

After drying and seed cleaning, seed samples from each plot in all trials were analysed for purity, thousand seed weight and germination in the seed laboratory at NIBIO Landvik.

Experimental series III. Chemical desiccators in white clover seed crops, 2020

Trials were carried out in cv. Litago at NIBIO Landvik (same location as in Experimental series I and II) and cv. Norstar at Gvarv (59°42′ N, 09°18′E) according to the same experimental plan as described for Experimental series II (Table 3), except for the swathing treatment (T 14). Gross plot size, number of blocks and spraying procedure were as described for Experimental series II.

Detailed information about the two trials, including weather conditions during the experimental period, can be found in Table 5. Both trials were harvested with Wintersteiger plot combines at a drum periphery speed of 30 m/s and a concave clearance of 6–7 mm in the front and 2–4 mm in the rear. Harvest plot size was 1.5 × 6.5 m. No sieves were installed during combining.

Registrations included seed crop colour at harvest and per cent water in the harvested seed mass as described for Experimental series I. The entire straw yield was weighed before taking a sample for dry matter determination. Seed cleaning and seed analyses were as described for Experimental series II.

Table 4. Dates for fungicide application, desiccation, swathing, colour assessment and seed harvest, including determination of per cent dry matter in straw and per cent water in the uncleaned seed yield, as well as temperature and precipitation during the harvest period in three red clover trials in 2020 (Experimental series II).

	Landvik	Svarstad	Våler
Date for fungi control with 1 l/ha Delaro SC 325	30 July	7 Aug.	10 Aug.
Date for early desiccation (Application date A)	2 Sep.	2 Sep.	22 Aug.
Date for late desiccation (Application date B)	10 Sep.	9 Sep.	31 Aug.
Swathing date (treatment (T 14)	10 Sep.	9 Sep.	No swathing
Date for colour assessment	17 Sep.	10 Sep.	3 Sep.
Date for seed harvest, determination of per cent dry matter in straw and per cent water in the uncleaned seed yield	17 Sep.	14 Sep.	3 Sep.
Mean temperature (°C) / Precipitation (mm) from the first application date (A) to seed harvest[a]	13.4 / 40	13.4 / 26	13.3 / 5
Mean temperature (°C) / Precipitation (mm) from the second application date (B) / swathing to seed harvest1	13.2 / 3	13.4 / 1	12.0 / 1
Seed yield (averaged across treatments), kg ha^{-1}	959	468	311

[a]Meteorological data from the weather stations located closest to the trials at Landvik, Svarstad and Våler in 2020. Distance from the trials were 0.5, 15 and 14 km, respectively.

Statistical analyses

All response variables presented in Tables 6–10 were tested for normality of residuals before performing the analyses of variances. We used the NORMALTEST option in the PROC CAPABILITY procedure to verify that the values had a normal distribution (Shapiro–Wilk test, Kolmogorov–Smirnov test, Anderson–Darling test and Cramér-von Mises test) (SAS Institute 2015).

For data failing the normality tests, including seed crop colour at harvest and the water content in uncleaned seed mass at Sandefjord (Table 6), seed crop colour at harvest at Landvik and Våler (Table 7), percentage of nomal seedlings, fresh seeds and germination capacity at Våler (Table 8) and green colour at harvest at Landvik and the dry matter percentage in straw at Gvarv (Table 9), log10-transformations were carried out before performing any analyses of variances.

For all the presented response variables (Tables 6–10), the analysis of variance (SAS Institute 2015) was performed either individually for each trial (with the three blocks as the random variable) or collectively for all trials. In the collective analyses, trial site was always regarded as a random variable. In all tables (6^{-1}0), significant differences between treatments are indicated by different letters for each response variable according to Duncan multiple comparison test at $P <$ 0.05.

Table 5. Dates for desiccation, colour assessment and seed harvest, including determination of per cent dry matter and yield of straw and per cent water in the uncleaned seed yield, as well as temperature and precipitation during the harvest period in two white clover trials in 2020 (Experimental series III).

	Landvik	Gvarv
Date for early desiccation (Application date A)	31 July	1 Aug.
Date for late desiccation (Application date B)	6 Aug.	7 Aug.
Date for colour assessment	12 Aug.	14 Aug.
Date for seed harvest and, determination of per cent dry matter and yield of straw and per cent water in the uncleaned seed yield	13 Aug.	14 Aug.
Mean temperature (°C) / Precipitation (mm) from the first application date (A) to seed harvest[a]	17. 8 / 17	17 .7 / 13
Precipitation (mm) from the second application date (B) to seed harvest[a]	18.7 / 1	18.9 / 0
Seed yield (averaged across treatments), kg ha^{-1}	226	119

[a]Meteorological data from the weather stations located closest to the trials at Landvik and Gvarv in 2020. Distance from the trials were 0.5 and 5 km, respectively.

Results

Experimental series I. Chemical desiccators in red clover seed crops, 2019

Seed crop colour

At Sandefjord, the colour of the plants at seed harvest (two weeks after the last spraying date) was significantly browner (more wilted) on plots sprayed with Reglone (T 14) compared to the other treatments. The plots sprayed with Beloukha twice (T 4) or in combination with Spotlight (T 8) or Glypper (T 9), or Vinegar twice (T 13), also had a wilted appearance (Table 6). The greenest plants at seed harvest were found on unsprayed plots (T 15) and plots sprayed with either Spotlight Plus (T 1 and T 2), Gozai (T 5 and T 6) or urea (T 10) (Table 6).

Also in Våler, plants sprayed with Reglone (T 14) were significantly browner than plants in all other treatments at seed harvest (Table 6). Among the alternative products, the strongest effect on colour was recorded for MCPA + Glypper (T 7) and Glypper + Beloukha (T 9). As in the trial in Sandefjord, spraying with urea fertilizer (T 10) had no colour effect on the red clover plants.

On average for the two trials, the most effective treatments 9 and 14 could not be separated significantly in terms of colour, while plants on plots sprayed with urea (T 10), Spotlight Plus (T 1 and T 2) and Gozai (T 5 and T 6) had almost the same green colour as the unsprayed plots (T 15) (Table 6).

Table 6. Effect of desiccation treatments on seed crop colour at harvest, plant dry matter percentage, water content in uncleaned seed, seed yield (kg ha^{-1}) and germination capacity (%) in red clover seed crops. Experimental series I (2019).

	Product application rate (L ha^{-1})		Seed crop colour (1-9, 9 is most brown/wilted) at harvest[1]			Dry matter (%) in plant mass at seed harvest		Water content (%) in uncleaned seed just after harvest	Seed yield (kg ha^{-1})	Thousand seed weight (mg)	Germinati on capacity (%)[3]
Treatments (T)	Sprayingdate A	Spraying date B	Sande-fjord	Våler	Mean	Våler	Land-vik	Sandefjord	Mean	Mean	Mean
No. of trials			1	1	2	1	1	1	3	3	3
1. Spotlight Plus	-	1.0	3.7 efg	4.0 de	3.8 cde	43 cd	43	25 ab	526	1890	90
2. Spotlight Plus	0.5	0.5	2.7 fg	3.7 de	3.2 de	43 cd	41	24 abc	505	1906	90
3. Beloukha	-	16.0	4.7 bcde	4.3 de	4.5 bcde	44 cd	44	16 cde	546	1881	92
4. Beloukha	16.0	16.0	6.7 abc	4.7 cd	5.7 bc	42 d	46	17 cde	503	1930	92
5. Gozai	-	0.8	3.3 efg	3.7 de	3.5 cde	48 bc	40	22 abc	529	1822	91
6. Gozai + Renol[2]	0.8	0.8	2.3 g	4.0 de	3.2 de	44 cd	43	21 abcd	490	1930	89
7. MCPA + Glypper	2.0 + 2.0	-	4.0 def	5.7 bc	4.8 bcde	52 b	45	14 de	465	1879	83
8. Beloukha + Spotlight	-	16.0	6 abcd	4.3 de	5.2 bcd	43 cd	43	20 abcd	523	1830	89
9. Glypper (early) + Beloukha (late)	2.0	16.0	7.0 ab	6.0 ab	6.5 ab	57 a	44	9 f	470	1882	91
10. Urea (46% N)	-	402	2.3 g	3.3 de	2.8 de	41 d	38	28 a	473	1939	90
11.Flex Urea N18	250	250	4.3 cde	-	-	-	-	-4	-	-	-
12.Flex N24	250	250	5.0 bcde	-	-	-	-	18 bcd	-	-	-
13. Vinegar (8.75% acetic acid)	500	500	6.3 abcd	-	-	-	-	17 bcd	-	-	-
14. Reglone (control)	-	2.5	9.0 a	7.0 a	8.0 a	60 a	41	12 ef	508	1879	91
15. No desiccation (unsprayed control)	-	-	2.3 g	3.0 e	2.7 e	44 cd	43	25 ab	506	1861	91
P-value			<.0001	<.0001	<.1	<.0001	>.05	<.0001	>.05	>.05	>.05

1 Seed crop colour was assessed visually according to a 1 to 9 scale, where 1 corresponded to 100% live red clover plants with green leaves and stems while 9 was completely withered plants with a brown colour. 2Urea: 40 kg N/ha. 3Germination capacity (%) including ungerminated fresh seeds and up to 20% hard seeds. 4Plots not harvested.

Table 7. Effect of various desiccation treatments on seed crop colour shortly before seed harvest and on per cent dry matter in straw and water content in uncleaned seed just after seed harvest in three red clover trials. Experimental series II (2020)

Treatments (T)	Product application		Seed crop colour (1-9, 9 is most brown/ wllted) at harvest[a]				Dry matter (%) in straw just after seed harvest				Water content (%) in uncleaned seed just after seed harvest			
	rate (Lha^{-1}) Spraying date A	Spraying date B	Landvik	Svarstad	Våler	Mean	Landvik	Svarstad	Våler	Mean	Landvik	Svarstad	Våler	Mean
Number of trials			1	1	1	3	1	1	1	3	1	1	1	3
1.Spotlight Plus	1	0	2.3 fg	4.7 ef	2.7 e	3.2 h	31 b	47 bcd	40 abcd	39	20 bc	15 ab	23 bc	19 bc
2.Harm. Leaf Active	250	250	8.1 ab	8.3 ab	8.0 a	8.1 a	34 b	48 bcd	46 a	43	15 def	13 bc	13 fg	14 cd
3.Harmonix FoliaPlus	120	120	8.4 a	9.0 a	-	-	34 b	54 bc	-	-	14 ef	10 d	-	-
4.Beloukha	0	16	5.2 bcde	6.3 cd	4.7 c	5.4 bcd	32 b	50 bcd	42 abcd	41	20 bc	12 cd	19 cd	17 bcd
5.Beloukha	16	16	5.7 abcd	7.3 bc	6.3 b	6.4 b	32 b	49 bcd	39 bcd	40	18 cde	12 cd	15 efg	15 cd
6.Vinegar, 8.75%	500	500	4.8 cde	6.3 cd	3.7 d	4.9 cde	33 b	51 bcd	38 cd	41	18 cde	11 cd	17 de	15 cd
7.Vinegar, 8.75%	0	500	3.5 ef	5.0 ef	2.7 e	3.7 efgh	34 b	46 cd	41 abcd	40	19 bcd	13 bc	22 bc	18 bc
8.Glypper	2	0	4.1 cde	4.7 ef	2.0 f	3.6 fgh	35 b	51 bcd	36 d	41	15 cdef	13 bc	23 b	17 bcd
9.Spotlight+Beloukha	1	16	5.6 abcde	7.0 c	6.0 b	6.2 bc	32 b	51 bcd	43 abc	42	18 cde	12 cd	14 efg	15 cd
10.Glypper+Beloukha	2	16	6.2 abc	7.3 bc	4.7 c	6.1 bcd	37 b	52 bcd	44 ab	44	12 f	12 cd	12 g	12 d
11.Flurostar	2	0	2.3 fg	3.0 g	2.0 f	2.4 h	34 b	44 d	39 bcd	39	26 a	17 a	34 a	26 a
12.Saltex, 22.5%	800	800	4.2 de	7.3 bc	3.0 de	4.8 def	33 b	56 b	42 abcd	44	18 cde	13 bc	17 def	16 cd
13.Saltex, 22.5%	0	800	4.9 cde	5.3 de	2.0 f	4.1 efg	33 b	51 bcd	40 abcd	41	19 bcd	13 bc	25 b	19 bc
14. Swathing	-	-	8.2 ab	7.3 bc	-	-	73 a	73 a	-	-	5 g	7 e	-	-
15. No desiccation or swathing (control)	0	2.0 g	4.0 fg	2.0 f	2.7 h	34 b	51 bcd	38 cd	41	22 b	14 bc	31 a	22 ab	
P-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.04	>.05	<.0001	<.0001	<.0001	<.01		

[a]Seed crop colour was assessed visually on a 1 to 9 scale, where 1 corresponded to 100% live red clover plants with green leaves and stems while 9 was completely withered plants with a brown colour.

Table 8. Effect of various desiccation strategies on seed yield and germination of red clover. Experimental series II (2020).

	Product application rate (L ha⁻¹)		Seed yield (kg ha⁻¹)				Germination analysis (Våler), %[a]						Thousand seed weight (mg)
Treatments (T)	Sprayingdate A	Spray ing date B	Landvik	Svarstad	Våler	Mean	Normal seedlings	Fresh seeds	Hard seeds	Abnormal seedlings	Dead seeds	Germination capacity[1]	
Number of trials			1	1	1	3	1	1	1	1	1	1	3
1.Spotlight Plus	1	0	973	501	318	597	47 a	0	34	10 bc	9	67 a	2002
2.Harm. Leaf Active	250	250	1013	449	321	594	45 a	1	32	11 bc	11	66 a	1956
3.Harmonix FoliaPlus	120	120	935	437		-	-	-	-	-	-	-	
4.Beloukha	0	16	978	474	344	598	54 a	1	26	9 c	11	75 a	1925
5.Beloukha	16	16	921	447	272	547	55 a	1	27	7 c	11	75 a	1965
6.Vinegar, 8.75 %	500	500	939	461	299	566	51 a	1	32	6 c	10	72 a	2032
7.Vinegar, 8.75 %	0	500	962	474	307	581	46 a	1	30	9 c	15	67 a	1994
8.Glypper	2	0	1003	493	310	602	43 a	1	29	16 ab	11	64 a	2005
9.Spotlight +Beloukha	1	16	920	447	325	564	47 a	1	32	9 c	11	68 a	1982
10.Glypper +Beloukha	2	16	974	515	336	608	33 b	0	37	20 a	10	53 b	2004
11.Flurostar	2	0	853	462	287	534	45 a	1	33	10 bc	10	66 a	2032
12.Saltex, 22.5 %	800	800	1017	415	324	585	48 a	1	29	10 bc	12	69 a	1943
13.Saltex, 22.5 %	0	800	936	485	333	585	48 a	2	31	8 c	11	70 a	1904
14. Swathing	-	-	963	455		-	-	-	-	-	-	-	-
15. No desiccation or swathing (control)	0	0	1002	486	265	584	56 a	1 bc	25 a	10 bc	8	76 a	1958
P-value			>.05	>.05	>.05	>.05	0.02	>.05	>.05	<.01	>.05	0.01	>.05

[a]Germination capacity (%) included ungerminated fresh seeds and up to 20 % hard seeds.

Table 9. Effect of various desiccation treatments on green colour (scale from 1 to 9[a]), % dry matter in plant mass and dry matter yield of straw and water content in uncleaned seed (%) just after seed harvest of white clover. Experimental series III (2020).

	Product application rate (L ha^{-1})		Green colour of leaves and stems (1-9) at seed harvest[a]			Dry matter in straw (%) just after seed harvest			Dry matter yield (kg ha^{-1}) of straw at seed harvest				Water content (%) in uncleaned seed just after harvest		
Treatments (T)	Spraying date A	Spraying date B	Landvik	Gvarv	Mean	Landvik	Gvarv	Mean	Landvik	Gvarv	Mean	Rel	Landvik	Gvarv	Mean
Number of trials			1	1	2	1	1	2	1	1	2	2	1	1	2
1.Spotlight Plus	1	0	3.5 c	3.7 c	3.6 cd	26.7 cd	26.6 b	26.7 bcde	3200 bc	5430	4320	92	31.0 de	35.0 b	33 bc
2.Harm. Leaf Active	250	250	5.5 a	3.7 c	4.6 bc	29.4 abc	26 b	27.7 bcde	2490 c	4590	3540	75	21.7 fgh	27.7 bc	24.7 de
3.Harmonix FoliaPlus	120	120	6.2 ab	6.0 a	6.1 a	32.8	39.7 a	36.3 a	2700 bc	3420	3060	65	17.3 gh	12.7 d	15.0 f
4.Beloukha	0	16	3.0 c	2.3 de	2.7 d	25.3 cd	29.1 b	27.2 bcde	3080 bc	6540	4810	102	33.7 de	35.3 b	34.5 b
5.Beloukha	16	16	3.8 bc	3.7 c	3.8 cd	24.7 cd	25.9 b	25.3 bcde	3410 bc	4000	3710	79	32.3 de	29 bc	30.7 bcd
6.Vinegar, 8.75%	500	500	3.5 c	3 cde	3.3 d	23.8 d	23.8 b	23.8 de	3280 bc	5400	4340	92	37.7 cd	33.7 b	35.7 b
7.Vinegar, 8.75%	0	500	3.7 c	2.0 e	2.8 d	24.7 cd	23.5 b	24.1 de	3640 b	6010	4830	103	44.3 bc	47.7 a	46.0 a
8.Glypper	2	0	3.0 c	3 cde	3.0 d	31.9 ab	27.3 b	29.6 bc	3550 bc	4830	4190	89	25 efg	30.3 bc	27.7 bcde
9.Spotlight+Beloukha	1	16	5.3 a	4.7 b	5 ab	28.6 abcd	27.4 b	28 bcde	2840 bc	4470	3660	78	27.0 ef	24.3 c	25.7 cde
10.Glypper+Beloukha	2	16	5.7 ab	5.7 a	5.7 ab	31.8 ab	28.4 b	30.1 b	2820 bc	4210	3510	75	16.0 h	24.3 c	20.2 ef
11.Flurostar	2	0	2.8 c	3.3 cd	3.1 d	24.9 cd	24.6 b	24.8 cde	3470 bc	5130	4300	91	54.0 a	46.7 a	50.3 a
12.Saltex, 22.5%	800	800	3.5 c	2.3 de	2.9 d	28.1 abcd	29.6 b	28.8 bcd	3090 bc	4140	3610	77	25.3 efg	31.3 bc	28.3 bcd
13.Saltex, 22.5%	0	800	2.8 c	2.3 de	2.6 d	27.2 bcd	26.6 b	26.9 bcde	3460 bc	5890	4680	100	30.7 de	32.0 bc	31.3 bcd
14. No desiccation (unsprayed control)	0	0	1.0 d	1.0 f	1.0 e	24.5 cd	22.3 b	23.4 e	4690 a	4710	4700	100	47.3 ab	49.3 a	48.3 a
P-value			<0.0001	0.0001	0.0001	0.01	0.02	0.03	<.01	>.05b	>.05	-	<.0001	<.0001	<.0001

[a]The colour of plant mass was visually assessed according to a 1 to 9 scale, where 1 corresponded to 100% live white clover plants with a natural green colour of leaves and stems while 9 was completely withered plants with a brown colour.
[b]*P*-value was .11.

Per cent dry matter in intact red clover plants at harvest

At Våler, the plant mass at seed harvest was driest on plots sprayed with Reglone (T 14), followed by plots sprayed with Glypper + Beloukha (T 9) (Table 6).

At Landvik, where the red clover plants had lost most of their leaves due to fungi, there was no significant difference in per cent dry matter between the treatments (Table 6).

Water content in the uncleaned seed mass just after harvest

The two treatments that had the driest and most withered plants, i.e. plots sprayed with Reglone (T 14) and the combination of Glypper (early) followed by Beloukha (late) (T 9) gave the lowest water content in the uncleaned seed mass at Sandefjord. The uncleaned seed from plots sprayed with Beloukha only (T 3 and T 4), MCPA + Glypper (T 7), Beloukha + Spotlight (T 8), vinegar (T 13) and the highest concentration of Flex also had a significantly lower water content than uncleaned seed from the unsprayed control treatment (Table 6).

At the other end of the scale, especially urea (T 10), but also Spotlight Plus (T 1 and T 2) and to some extent Gozai (T 5 and T 6) had no or negligible effect on the water content of uncleaned seed compared to the unsprayed plots (T 15) (Table 6).

Seed yield

There were no significant seed yield differences between the various treatments at either Landvik, Sandefjord or Våler. Only the mean values are therefore shown in Table 6.

Thousand seed weight and germination

On average for all trials, the different treatments had no significant effect on either thousand seed weight or germination capacity (Table 6).

Experimental series II. Swathing and chemical desiccators in red clover seed crops, 2020

Seed crop colour

Among the directly harvested treatments at Landvik and Svarstad, the seed crops were significantly browner / more withered after being sprayed with Harmonix LeafActive (T 2) and especially Harmonix FoliaPlus (T 3) than in any other treatment (Table 7, Photo 1). Swathed plots (T 14) were also dark brown at Landvik (Table 7). At Våler, the colour effect of Harmonix LeafActive was significantly better than for the other products (Table 7).

Table 10. Effect of various desiccation treatments on seed yield and germination of white clover. Experimental series III (2020).

Treatments (T)	Product application rate (L ha^{-1}) Spraying date A	Spraying date B	Seed yield (kg ha^{-1}) Land-vik	Seed yield Gva-rv	Seed yield Mean	Rel	Germination analysis (%) Normal seedlings	Hard seeds	Fresh seeds	Abnormal seedlings	Deadseeds	Germination capacity[a]	Thousand seed weight (mg)
Number of trials			1	1	2	2	2	2	2	2	2	2	2
1.Spotlight Plus	0.1	0	256 ab	118	187 ab	126	59 abc	13	5	7 e	17 ab	77 abcd	718
2.Harm. Leaf Active	25	25	279 a	129	204 a	138	61 abc	13	4	10 bcd	12 de	78 abc	695
3.Harmonix FoliaPlus	12	12	265 a	152	209 a	141	61 abc	13	3	12 bc	12 cde	77 abcd	710
4.Beloukha	0	1.6	249 ab	130	189 ab	128	56 abc	20	4	7 e	13 bcde	80 a	704
5.Beloukha	1.6	1.6	233 ab	127	180 ab	122	63 ab	17	4	7 de	11 e	82 a	709
6.Vinegar, 8.75%	50	50	210 abc	141	176 abc	119	59 abc	17	3	9 cde	11 e	80 ab	701
7.Vinegar, 8.75%	0	50	174 bc	74	124 d	84	53 cd	20	3	11 bcd	14 bcde	76 abcd	715
8.Glypper	0.2	0	223 abc	109	166 abcd	112	47 d	15	4	19 a	15 abcde	66 e	696
9.Spotlight+Beloukha	0.1 + 0	0 + 1.6	231 abc	138	185 ab	125	64 a	15	2	7 e	14 bcde	80 a	708
10.Glypper+Beloukha	0.2 + 0	0 + 1.6	263 a	116	190 ab	128	57 abc	13	4	15 ab	11 e	74 bcd	709
11.Flurostar	0.2	0	150 c	107	129 cd	87	54 bcd	14	4	11 bcd	19 a	73 cd	599
12.Saltex, 22.5%	80	80	238 ab	136	187 ab	126	57 abc	12	3	12 bc	16 abcd	72 d	710
13.Saltex, 22.5%	0	80	178 bc	106	142 bcd	96	59 abc	16	2	9	16 abc	76 abcd	692
14. No desiccation (unsprayed control)	0	0	209 abc	88	148 bcd	100	56 abcd	21	3	7 e	13 bcde	80 a	713
P-value			0.03	>.05	0.02	-	0.05	>.05	>.05	<.01	0.02	<.01	>.05

[a]Germination capacity included ungerminated fresh seeds and up to 40% hard seeds.

On average for three sites, the treatments involving Beloukha, either alone (T 5) or when succeeding Spotlight Plus (T 9) or Glypper (T 10), also achieved acceptable colour rankings (Table 7). However, only the two Harmonix products (T 2 and T 3) changed the colour of both leaves and stems (Photo 2).

There was some natural colour loss of the clover plants, especially at Svarstad, where the colour of the unsprayed control plots was rated at 4, i.e. twice the rating of corresponding plots in the other two trials. The least effective desiccators (greenest plants), on average for all three trials, were Spotlight Plus (T 1), Flurostar (T 11) and Glypper alone (T 8) (Table 7).

Per cent dry matter in straw just after harvest

At Landvik and Svarstad, the red clover straw was significantly drier on plots swathed before harvest (T 14) than in the other treatments. Compared to unsprayed plots, none of the desiccants increased straw dryness in these trials (Table 7).

At Våler, the plots sprayed with Harmonix LeafActive (T 2) had the highest dry matter content (46%), followed by plots sprayed with Beloukha in combination with either Glypper (T 10) or Spotlight Plus (T 9) (43-44%). The lowest dry matter percentage at Våler was found in straw from unsprayed plots (T 15) and from plots sprayed early with either Glypper (T 8) or Flurostar (T 11) (Table 4).

Water content in the uncleaned seed mass just after harvest

Uncleaned seed from swathed plots (T 14) had significantly lower water content than uncleaned seed from directly combined plots at Landvik and Svarstad (Table 7). Of the directly combined plots, the lowest seed water content was found with Glypper + Beloukha (T 10) and with the Harmonix products (FoliaPlus at Landvik and Svarstad and LeafActive at Våler).

Spraying with Flurostar (T 11) did not reduce the seed water content compared to unsprayed plots (T 15) in any of the three trials (Table 7). Likewise, the early spraying with Spotlight Plus (T 1), late spraying with Saltex (T 13) and late spraying with vinegar (T 7) had a marginal effect (seed water content 18^{-1}9%) compared to the unsprayed plots (22%) on average for the three trials.

Seed yield, thousand seed weight and germination

There was no significant seed yield difference between the various treatments at either Landvik, Svarstad or Våler (Table 8).

Significant differences in germination capacity were found among the treatments at Våler (Table 8), but not at Svarstad or Landvik (data not shown). Significantly reduced germination capacity at Våler, mainly due to a high number of abnormal seedlings, was found in

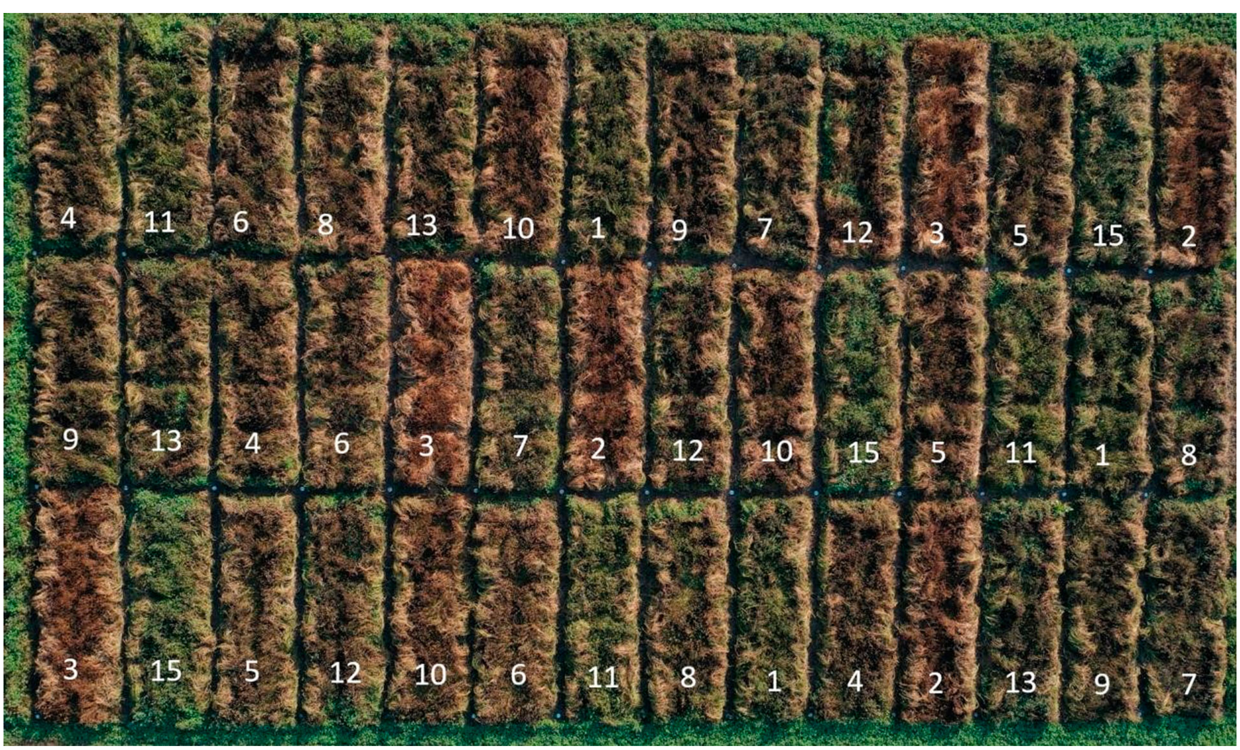

Photo 1. Aerial photo of the trial at Landvik shortly before seed harvest on 17 September 2020. Numbers refer to the treatments in Table 3. Swathed plots (T 14) were not included in the photo. Photo: Lars T. Havstad.

Photo 2. Plot desiccated twice with Harmonix FoliaPlus (T 3, left) or Beloukha (T 5, right). Photo was taken on 15 September 2020, two days before seed harvest at Landvik. Photos: Lars T. Havstad.

seeds from plots sprayed with Glypper alone (T 8), and even more when Glypper was followed by Beloukha (T 10, Table 8).

On average for all trials, the different treatments had no significant effect on thousand seed weight (Table 8).

Experimental series III. Chemical desiccators in white clover seed crops, 2020

Seed crop colour

Compared to the unsprayed control plots, a browner colour was seen on all desiccated plots at both Landvik and Gvarv. On average for the two trials, Harmonix FoliaPlus (T 3) produced the least green plots, followed by Glypper + Beloukha (T 10) (Photos 3 and 4, Table 9).

On average for two trials, the poorest effect of desiccants (greenest colour) was seen with one or two applications of Saltex (T 12 and T 13), one application of Beloukha (T 4) and one application of Vinegar (T 7).

Per cent dry matter and yield of straw at seed harvest

Shortly after seed harvest, the white clover straw was driest on plots sprayed with Harmonix FoliaPlus (T 3) at both Landvik and Gvarv (Table 9). However, at Landvik per cent dry matter in the straw from these plots could not be separated significantly from plots sprayed with Harmonix LeafActive (T 2), Spotlight + Beloukha (T 9) and early with Glypper, either alone (T 8) or later with Beloukha (T 10). On average for both trials, the dry matter content was 36.3% on plots sprayed with Harmonix FoliaPlus (T 3), and between 23.4% (T 15) and 30.1% (T 10) in the other desiccation treatments (Table 9).

At Landvik, a significantly higher yield of straw was found on unsprayed control plots then on desiccated plots (Table 9). While the differences between desiccated treatments were mostly insignificant, it is noteworthy that the lowest yields (42-47% lower than on unsprayed plots) were harvested on plots sprayed with Harmonix LeafActive and Harmonix FoliaPlus (T 2 and T3 (Table 9). At Gvarv there was also a trend ($P = 0.11$), to lower dry matter yield on plots sprayed with Harmonix FoliaPlus (27% less than on unsprayed control plots, Table 9).

Water content in the uncleaned seed mass just after harvest

At Gvarv the uncleaned seed yield had the lowest water content on plots sprayed twice with Harmonix FoliaPlus (T 3, Table 9). The same treatment also resulted in the driest seed at Landvik, although not significantly different from Harmonix LeafActive (T 2) and Glypper + Beloukha (T 10).

Compared with unsprayed plots, early spraying with Flurostar (T 11) and late spraying with Vinegar (T 7) had no or negligible effect on the water content of the uncleaned seed mass. For these treatments, the water content, on average for the two fields, was between 46.0 and 50.3% (Table 9).

Seed yield, thousand seed weight and germination

The highest seed yield at Gvarv was harvested on plots sprayed with Harmonix FoliaPlus (T 3) (73% higher seed yield than on unsprayed plots). However, the

Photo 3. Plot sprayed six days earlier with Harmonix FoliaPlus (T 3) (left). Untreated plot (T 15) to the right. Photo from Landvik taken on 6 August 2020 by Lars T. Havstad.

Photo 4. Aerial photo of the white clover trial at Gvarv on 12 August 2020 (two days before seed harvested). Numbers refer to the treatments in Table 3. Photo: Knut H. Solhaug.

Table 11. Effect of various desiccation treatments on seed yield and germination of white clover. Experimental series III (2020).

Treatments (T)	Product application rate (L ha^{-1})		Seed yield (kg ha^{-1})				Germination analysis (%)					
	Spray- ing date A	Spray-ing date B	Landvik	Gvarv	Mean	Rel	Normal seedlings	Hard seeds	Fresh seeds	Abnormal seedlings	Dead seeds	Germination capacity[a]
Number of trials			1	1	2	2	2	2	2	2	2	2
1.Spotlight Plus	0.1	0	256 ab	118	187 ab	126	59 abc	13	5	7 e	17 ab	77 abcd
2.Harm. Leaf Active	25	25	279 a	129	204 a	138	61 abc	13	4	10 bcd	12 de	78 abc
3.Harmonix FoliaPlus	12	12	265 a	152	209 a	141	61 abc	13	3	12 bc	12 cde	77 abcd
4.Beloukha	0	1.6	249 ab	130	189 ab	128	56 abc	20	4	7 e	13 bcde	80 a
5.Beloukha	1.6	1.6	233 ab	127	180 ab	122	63 ab	17	4	7 de	11 e	82 a
6.Vinegar, 8.75%	50	50	210 abc	141	176 abc	119	59 abc	17	3	9 cde	11 e	80 ab
7.Vinegar, 8.75%	0	50	174 bc	74	124 d	84	53 cd	20	3	11 bcd	14 bcde	76 abcd
8.Glypper	0.2	0	223 abc	109	166 abcd	112	47 d	15	4	19 a	15 abcde	66 e
9.Spotlight+Beloukha	0.1 + 0	0 + 1.6	231 abc	138	185 ab	125	64 a	15	2	7 e	14 bcde	80 a
10.Glypper+Beloukha	0.2 + 0	0 + 1.6	263 a	116	190 ab	128	57 abc	13	4	15 ab	11 e	74 bcd
11.Flurostar	0.2	0	150 c	107	129 cd	87	54 bcd	14	4	11 bcd	19 a	73 cd
12.Saltex, 22.5%	80	80	238 ab	136	187 ab	126	57 abc	12	3	12 bc	16 abcd	72 d
13.Saltex, 22.5%	0	80	178 bc	106	142 bcd	96	59 abc	16	2	9	16 abc	76 abcd
14. No desiccation (unsprayed control)	0	0	209 abc	88	148 bcd	100	56 abcd	21	3	7 e	13 bcde	80 a
P-value			0.03	>.05	0.02	-	0.05	>.05	>.05	<.01	0.02	<.01

[a]Germination capacity included ungerminated fresh seeds and up to 40% hard seeds.

difference between treatments was not significant. Plots sprayed with Harmonix LeafActive (T 2), Harmonix FoliaPlus (T 3) and Glypper + Beloukha late (T 10) gave the highest seed yield (26-33% more than unsprayed plots) at Landvik (Table 10).

On average for the two trials, the lowest seed yield was saved on plots having the moistest seed mass, ie unsprayed plots (T 15) and plots sprayed either early with Flurostar (T 11) or late with vinegar (T 7) (Table 10).

The different treatments had no significant effect on thousand seed weight (Table 11), but there were significant differences in germination capacity (Table 10). The lowest germination capacity, 66% on average for both trials, was found in the seeds from plots sprayed with Glypper alone (T 8). The reason for the low germination capacity was a high proportion of dead seeds and abnormal seedlings. The overall thousand seed weight, averaged for all treatments and both trials, was 0.698 g.

Discussion

The decision to ban diquat has been a challenge for growers of clover seed, potatoes and other crops that depend on desiccation before harvest (Farmers guide, 2019). In the search for alternative strategies, Experimental series II showed swathing to be the most efficient method to dry red clover seed crops before harvest. Good drying conditions and the use of equipment that left plants in open, upright windrows contributed to fast drying of the crop as a whole and of the seed heads in particular (Table 7). In practical red clover seed production, avoiding large and compact windrows (Havstad & Susort, 2012) by using finger bar cutters similar to that used in the trial at Landvik may therefore be beneficial to speed up the drying process, especially after unexpected rain between swathing and harvest. Fast drying is crucial as the complete seed yield may be lost if a swathed crop is left in the field for a long period under wet and humid conditions (Boelt, 2002).

Although not included in Experimental series III, previous trials have shown swathing to be an acceptable alternative to desiccation even in white clover (Havstad et al., 2016). While in Danish white clover seed production, swathing is often preceded by desiccation with MCPA to prevent unwanted regrowth (Boelt, 2012), applications for a minor use registration of MCPA for desiccation of white clover seed crops has so far been rejected by the Norwegian Food Safety Authority. However, some studies have shown that swathing may lead to more seed losses and lower seed yields compared with direct combining after desiccation with diquat (Chynoweth et al., 2020). To minimize seed loss, the swathed material should preferably be harvested with a pick-up header rather than with a conventional header (Westlin & Johansson, 2021). With these modifications for white clover, swathing is likely to become more common in clover seed production in Norway, as well as in the other Nordic countries (Moll, 2020), in the years to come.

For plots harvested directly after desiccation, Experimental series I (2019) showed that none of the alternative products or product combinations desiccated red clover better than diquat. In 2020, when an application to include Reglone as a control treatment in Experimental series II and III was turned down by the Food Safety Authority, the most promising alternative desiccants were the Harmonix-products; FoliaPlus and LeafActive in red clover (Table 7) and FoliaPlus in white clover (Table 9). With two applications, these products caused the strongest colour changes in both clover species in 2020. In white clover, the visual impression was also confirmed by the finding that the straw dry matter content was higher and the straw yield lower with FoliaPlus than in any other treatment. In red clover, more surprisingly, none of the Harmonix products dried down the straw and seed mass (Table 7) as good as expected based on the colour assessments (Table 7). The reason for this is not clear but might have to do with lodged crops that prevented the products from getting into contact with the entire plant mass.

Although the colour observations were more convincing than the documented dryness of the crop, the results from Våler (Table 7), where the straw was driest after spraying with Harmonix LeafActive, and from Svarstad, where the water content of the uncleaned seed was lowest after spraying with Harmonix FoliaPlus, add to the conclusion that the Harmonix-products are promising alternatives to Reglone in clover seed production. The response to these desiccants was indeed very fast as a visible wilting effect could usually be seen within a few hours after application. According to sales information (Bayer, 2021), the active ingredients, pelargonic acid in FoliaPlus and acetic acid in LeafActive, work in combination with a protein-based compound called NWS Booster, which increases the desiccation effect of both products. Bayer Crop Science A/S is currently working on an improved version of LeafActive for more efficient desiccation (Andersen, 2021).

Another promising strategy with regard to the dryness of straw and uncleaned seed in red (Table 6 and 7) as well as white clover (Table 9), was an early application of glyphosate followed by Beloukha a week later.

However, with its current EU registration expiring in December 2022 (European commission, 2022), the future of glyphosate on the European market seems rather uncertain. The poor germination capacity of seeds sprayed with glyphosate, either when preceding Beloukha in the red clover trial at Våler (Table 8) or when used alone in the white clover trials (Table 10), is another argument against using glyphosate as a desiccant in clover seed crops. A negative impact of glyphosate on germination has also been shown in previous laboratory experiments with red clover (Salazar and Appleby,1982).

Although inferior to the Harmonix-products, two applications of Beloukha had an acceptable effect on seed crop colour, per cent dry matter of intact plants or straw and the water content of the uncleaned seed. This is not surprising as Beloukha contains pelargonic acid, i.e. the same active ingredient as Harmonix FoliaPlus, albeit without a booster to enhance the acid effect on plant tissues. Beloukha was also considered as the best alternative to diquat in recent Swedish red clover trials that did not include the two Harmonix products (Moll 2020).

Both Beloukha and the two Harmonix products were sprayed at their maximum recommended rates. Consequently, the amount of pelargonic acid on each spraying date was about three times higher when using Harmonix FoliaPlus than when using Beloukha. Since these and other products based on organic acids are usually expensive (Neal, 2018), further research to optimize spraying rates and application intervals would probably be of great economic importance for the clover seed growers.

The products Gozai and Spotlight Plus which were the most promising desiccators in recent potato experiments, and later accepted for use in the potato industry in Norway (Glorvigen and Abrahamsen, 2020), had no or only minimal desiccation effect in the present clover seed study. Thus, neither mixing Spotlight Plus with a strong adjuvant (5.0 L ha^{-1} Mero oil) in experiments 2 for better contact, leaf penetration and coverage (Curran, 2009) or advancing the application date (Glorvigen and Abrahamsen, 2020) from one (spraying date B in experiment 1) to two weeks (spraying date A in experiment 2) before harvest, had any beneficial impact.

Inadequate desiccation after using Spotlight Plus and Gozai was also reported in a similar Swedish study in red clover seed crops (Moll, 2020).

Also spraying with different urea-based fertilizers, at different rates and application dates (experiment I), and early spraying with Flurostar (fluroxypyr) (experiment II and III) had too little desiccation effect on the clover crops to be an alternative for diquat. Although the early plus late application of Saltex or Vinegar resulted in acceptable dryness of both plant and seed mass in some trials in experiment II and III (e.g. Table

7), these products gave, overall, a poorer desiccation than the Harmonix-products and the double spraying treatment with Beloukha.

The white clover seed yield at Landvik (Table 5) was on the same level as the five-year average (Havstad & Aamlid, 2021). At Gvarv, it was about 40% lower which may be due to rather cold and humid conditions during pollination at this location. The mean temperature for July 2020 was 1.8°C below the 30-year normal and the precipitation as much as 58% above the normal at this site.

In red clover, the overall seed yield level was always higher than the five-year normal for diploid cultivars (Havstad & Aamlid, 2021) for all trials both in 2019 (Table 2) and 2020 (Table 4). Especially high seed yields, 4–5 times higher than the five-years average, was harvested at Landvik in 2020 (Table 4) and Våler in 2019 (Table 2). This was mainly due to good conditions during pollination and seed harvesting.

As the white clover plants produce new green leaves and flower heads throughout the growing season, desiccation is even more important in this species than in red clover, which tends to wither naturally in autumn. Accordingly, the dryness of plant and seed mass at harvest highly affected the white clover seed yield (Table 10), with the highest and lowest seed yields usually harvested on plots having the driest and moistest plants, respectively. This can be explained by better separation of the seeds from the seed heads when threshing dry plants.

In red clover, on the other hand, only small and insignificant seed yield differences were found despite variation between treatments both for plant and seed mass dryness, especially in trials where leaves were intact at harvest (excluding the fungi infested trial at Landvik in 2019). The reason for the small seed yields differences may be due to the use of plot combiners without sieves in the on-farm trials, and the use of a conventional combiner with wide sieve openings (10 mm) at Landvik. In the practical seed production, where a 4–5 mm bottom sieve is often used, more seeds would probably have been lost on the plots with the moistest plant mass (Aamlid and Øverland, 2018). However, the experiments indicate that it is possible to achieve acceptable seed yields also in seed crops that have not been swathed or desiccated if sieve openings are adjusted and more residues are tolerated in the harvested seed mass.

Thousand seed weight was not significantly affected by the various desiccation treatments compared to unsprayed control plots either in red (Tables 6 and 8) or white (Table 10) clover. This is in concurrence with Kirk et al (2017) and indicate that the accumulation of seed reserves was not negatively affected by the various desiccation treatments.

All in all, swathing before harvest, using finger bar cutters, seems to be the most effective drying method under favourable weather conditions. While none of the tested chemicals were superior to diquat, the most promising alternatives were Harmonix FoliaPlus or Harmonix LeafActive in red clover and Harmonix FoliaPlus in white clover. Although usually less effective than these products, Beloukha also had an acceptable effect, especially when sprayed both early and late. The early spraying of Glypper followed by Beloukha after one week also resulted in acceptable desiccation, but this treatment cannot be recommended due to the risk for reduced germination capacity of the clover seed. No other product desiccated the crops sufficiently to be consider for use in clover seed production.

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