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 or late at 50% mature seed heads. Products included, either for one or two years, was Spotlight Plus (carfentrazone-ethyl), Beloukha (pelargonic acid), Glypper (glyphosate), Gozai (pyralufen-ethyl), Harmonix LeafActive (acetic acid), Harmonix FoliaPlus (pelargonic acid), Flurostar (fluoroxypry) 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.

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 However, the long-lasting approval of diquat (introduced in Norway in 1964) was withdrawn on 4 February 2020, both in Norway and in the EU.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 safufenacil (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: carfentrazone), Beloukha (active substance: pelargonic acid), Gozai (active substance: pyralufen-ethyl), Harmonix LeafActive (active substance: acetic acid), Harmonix FoliaPlus (active substance: pelargonic acid), Flurostar (active substance: fluoroxypry) 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 (Suttén & Foy, 1971), most of the available contact herbicides, such as carfentrazone-ethyl (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, fluoroxyprpyr 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). |
|-----------------------------------------------|
| **Treatments (T)** | **Product application rate (L ha\(^{-1}\))** | **Active ingredient rate (kg ha\(^{-1}\))** | **Application date A** | **Application date B** |
| 1 | Spotlight Plus (60 g L\(^{-1}\) carfentrazone-ethyl) (no adjuvant) | 10\(^{-4}\) days before seed harvest (ca 50% of seed heads matured). | 1.0 / 0.06 |
| 2 | Spotlight Plus + DP\(^{a}\) | 5-7 days before seed harvest (ca 65% of seed heads matured). | 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 |
| 5 | Gozai (26.5 g L\(^{-1}\) pyraflufen-ethyl) + Renol\(^{b}\) | | 0.8 / 0.02 |
| 6 | Gozai + Renol\(^{c}\) | | 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 | 16.0 / 10.88 + 1.0 / 0.06 |
| 8 | Beloukha + Spotlight (no adjuvant) | | 16.0 / 10.88 |
| 9 | Glypper (early) + Beloukha (late) (no adjuvant) | | 2.0 / 0.72 |
| 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). cUrea: 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.

**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,
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 Drongningborg 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 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 x 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 3. Experimental plan, including product rates (L ha\(^{-1}\)), active ingredients (kg ha\(^{-1}\)) and application volumes 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\(^{-1}\)) | Application date A | Application date B | Application volume (L ha\(^{-1}\) (Date A + B)) |
|---------------|-------------------------------------------------|------------------|------------------|---------------------------------|
| 1 Spotlight Plus (60 g L\(^{-1}\) carfentrazone-ethyl) | 1.0 / 0.06 | 10-14 days before seed harvest (ca 50 % of seed heads mature) | 5-7 days before seed harvest (ca 65 % of seed heads mature) | 300 + 0 |
| 2 Harmonix Leaf Active (240 g/L acetic acid) (no adjuvant) | 250.0 / 60.00 | 250.0 / 60.00 | 1000 + 1000 |
| 3 Harmonix FoliaPlus (250 g L\(^{-1}\) pelargonic acid) (no adjuvant) | 12.0 / 30.00 | 12.0 / 30.00 | 12.0 / 30.00 |
| 4 Beloukha (680 g L\(^{-1}\) pelargonic acid) (no adjuvant) | - | 16.0 / 10.88 | 500 + 500 |
| 5 Beloukha (no adjuvant) | 16.0 / 10.88 | 16.0 / 10.88 | 0 + 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 oil\(^{a}\)) + 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\(^{-1}\) fluorokysypyr) (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\(^{-1}\).
**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).

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

*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 normal 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 (6−10), significant differences between treatments are indicated by different letters for each response variable according to Duncan multiple comparison test at $P < 0.05$.

**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).

| Treatments (T) | Spraying date A | Spraying date B | 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\(^{-1}\)) Mean | Thousand seed weight (mg) Mean | Germination capacity (%)\(^3\) 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 bcd e | 4.3 de | 4.5 cde | 44 cd | 44 | 16 cde | 546 | 1881 | 92 |
| 4. Beloukha | 16.0 | 16.0 | 6.7 abc | 4.7 cd | 5.7 bcde | 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 bcd | 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 | - | - | - | - | - | - |
| 12. Flex N24 | 250 | 250 | 5.0 bcde | - | - | - | - | - | - |
| 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. \(^2\)Urea: 40 kg N/ha. \(^3\)Germination capacity (%) including ungerminated fresh seeds and up to 20% hard seeds. \(^4\)Plots 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 rate (Lha⁻¹) | Spraying date A | Spraying date B | Number of trials | Seed crop colour (1-9, 9 is most brown/ wilted) at harvest | Dry matter (%) in straw just after seed harvest | Water content (%) in uncleaned seed just after seed harvest |
|----------------|----------------------------------|-----------------|-----------------|-----------------|--------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------|
|                |                                  |                 |                 |                 | Landvik | Svarstad | Våler | Mean | Landvik | Svarstad | Våler | Mean | Landvik | Svarstad | Våler | Mean |
| 1. Spotlight Plus | 1.0 | 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 abcd | 7.0 c | 6.0 b | 6.2 bc | 32 b | 51 bcd | 43 abcd | 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. Fluorostar | 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 <.0001 <.0001 <.01

*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).

| Treatments (T)                          | Product application rate (L ha⁻¹) | Seed yield (kg ha⁻¹) | Germination analysis (Våler), %<sup>a</sup> | Thousand seed weight (mg) |
|----------------------------------------|-----------------------------------|----------------------|---------------------------------------------|--------------------------|
|                                        | Sprayingdate A | Sprayingdate B | Landvik | Svarstad | Våler | Mean | Normal seedlings | Fresh seeds | Hard seeds | Abnormal seedlings | Dead seeds | Germination capacity<sup>1</sup> |
| 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                           | 1                  | 16                 | 920     | 447      | 325   | 564  | 47 a               | 1            | 32         | 9 c                 | 11          | 68 a                  | 1982 |
| 10. Glypper + Beloukha                 |                    |                    |         |          |       | -    | -                  | -            | -          | -                   | -           | -                    | -    |
| 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            | 25         | 10 bc               | 8           | 76 a                  | 1958 |

P-value:<br>.05 | .05 | .05 | .05 | .02 | .05 | .05 | <.01 | .05 | 0.01 | >.05

<sup>a</sup>Germination capacity (%) included ungerminated fresh seeds and up to 20 % hard seeds.
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 mass 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.

Seeds and seed quality

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 was completely wilted plants with a brown colour.

Table 6. Effect of various desiccation treatments on green colour (scale from 1 to 9), % 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).

| Treatment (T) | Product application rate (L ha⁻¹) | Green colour of leaves and stems (1-9) at seed harvesta | 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 |
|--------------|----------------------------------|-------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|              | Spraying date A | Spraying date B | Landvik | Gvarv | Mean | Landvik | Gvarv | Mean | Landvik | Gvarv | Mean | Landvik | Gvarv | Mean | Rel | Landvik | Gvarv | Mean |
| 1. Spotlight Plus | 1 | 0 | 3.5 c | 3.7 c | 3.6 cd | 26.7 cd | 26.6 b | 27.7 bcde | 3200 bc | 4470 3660 78 27.0 ef | 24.3 c | 25.7 cde |
| 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 ... gh |
| 3. 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 |
| 4. 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 |
| 5. Vinegar, 9.5% | 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 ab | 28.3 bcd |
| 6. Glypper | 2 | 16 | 5.3 a | 4.7 b | 5 ab | 28.6 abcd | 27.4 b | 28 bcde | 2840 bc | 4470 3660 78 25.3 efg | 24.3 c | 25.7 cde |
| 7. 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 |
| 8. Flex Star | 14 | 125 | 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 |
| 9. 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 |
| 10. No desiccation (unsprayed control) | 0 | 0 | 1.0 d | 1.0 f | 1.0 e | 24.5 cd | 22.3 b | 23.4 cde | 4690 a | 4710 4700 100 47.3 ab | 49.3 a | 48.3 a | 0.0001 | P-value <0.0001 |
| 11. Saltex, 11.5% | 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 |
| 12. Ethof gent, 11.5% | 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. Ethof gent, 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 |
| 14. No desiccation (unsprayed control) | 0 | 0 | 1.0 d | 1.0 f | 1.0 e | 24.5 cd | 22.3 b | 23.4 cde | 4690 a | 4710 4700 100 47.3 ab | 49.3 a | 48.3 a | 0.0001 | P-value <0.0001 |

aThe 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 was completely wilted plants with a brown colour.

Table 7. Thousand seed weight and germination capacity in white clover. Experimental series III (2020).

| Treatment (T) | Thousand seed weight (g) | Germination capacity (%) |
|--------------|--------------------------|--------------------------|
| 1. Spotlight Plus | 2100 | 65 |
| 2. Harm. Leaf Active | 2100 | 65 |
| 3. Beloukha | 2100 | 65 |
| 4. Vinegar, 8.75% | 2100 | 65 |
| 5. Vinegar, 9.5% | 2100 | 65 |
| 6. Glypper | 2100 | 65 |
| 7. Glypper+Beloukha | 2100 | 65 |
| 8. Flex Star | 2100 | 65 |
| 9. Saltex, 22.5% | 2100 | 65 |
| 10. No desiccation (unsprayed control) | 2100 | 65 |
| 11. Saltex, 11.5% | 2100 | 65 |
| 12. Ethof gent, 11.5% | 2100 | 65 |
| 13. Ethof gent, 22.5% | 2100 | 65 |
| 14. No desiccation (unsprayed control) | 2100 | 65 |
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<sup>-1</sup>) | Seed yield (kg ha<sup>-1</sup>) | Germination analysis (%) | Thousand seed weight (mg) |
|---------------|---------------------------------------------|---------------------------------|--------------------------|---------------------------|
|               | Spraying date A | Spraying date B | Landvik | Gvarv | Mean | Normal seedlings | Hard seeds | Fresh seeds | Abnormal seedlings | Deadseeds | Germination capacity<sup>a</sup> |
| 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 ab | 141 | 176 ab | 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 ab | 109 ab | 166 | 112 | 47 d | 15 | 4 | 19 a | 15 abcde | 66 e | 696 |
| 9. Spotlight+Beloukha | 0.1 + 0 | 0 + 1.6 | 231 ab | 138 ab | 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 cd | 129 cd | 87 | 54 bcd | 14 | 4 | 11 bcd | 19 a | 73 cd | 599 |
| 12. Saltex, 22.5% | 80 | 80 | 238 ab | 136 cd | 187 ab | 126 | 57 abc | 12 | 3 | 12 bc | 16 abcde | 72 d | 710 |
| 13. Saltex, 22.5% | 0 | 0 | 178 bc | 106 | 142 | 96 | 59 abc | 16 | 2 | 9 | 16 abc | 76 abcd | 692 |
| 14. No desiccation (unsprayed control) | 0 | 0 | 209 ab | 88 ab | 148 | 100 | 56 abcd | 21 | 3 | 7 e | 13 bcde | 80 a | 713 |

<sup>a</sup>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 Spot-light 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 18–19%) 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
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 than 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 T 3 (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

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**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.
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.
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 & Susrot, 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 time under wet and humid conditions (Boelt, 2002). Although not included in Experimental series III, previous trials have shown that swathing is effective in preventing seed production and regrowth of white clover (Havstad et al., 2016). While in Danish white clover production, swathing has been reported to increase seed yield and improve seed quality (Havstad & Susrot, 2012) by using finger bar cutters, similar to that used in the trial at Landvik, it may be beneficial to speed up the drying process. 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 practical red clover seed production, avoiding large and compact windrows (Havstad & Susrot, 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 time under wet and humid conditions (Boelt, 2002).

### 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 date A | Spray date B | Landvik | Grav | Mean | Rel | Normal seedlings | Hard seeds | Fresh seeds | Abnormal seedlings | Dead seeds | Germination capacity |
| 1. Spotlight Plus | 0.1 | 0 | 256 ab | 118 | 187 a | 126 | 59 abc | 13 | 5 | 7 e | 17 ab | 77 abc | cd |
| 2. Harmonix Leaf Active | 25 | 25 | 279 a | 129 | 204 a | 138 | 61 abc | 13 | 4 | 10 bcd | 12 de | 78 abc | 3 |
| 3. Harmonix FoliaPlus | 12 | 12 | 265 a | 152 | 209 a | 141 | 61 abc | 13 | 3 | 12 bc | 12 cde | 77 abc | 3 |
| 4. Beloukha | 0 | 1.6 | 249 ab | 130 | 189 ab | 128 | 56 abc | 20 | 4 | 7 e | 13 bcde | 80 a | 4 |
| 5. Beloukha | 1.6 | 1.6 | 233 ab | 127 | 180 ab | 122 | 63 ab | 17 | 3 | 9 cd | 11 e | 82 a | 4 |
| 6. Vinegar, 8.75% | 50 | 50 | 210 abc | 141 | 176 abc | 117 | 53 ab | 20 | 3 | 11 bcd | 14 bcde | 76 abc | 4 |
| 7. Vinegar, 8.75% | 0 | 1.6 | 174 bc | 94 | 124 bc | 78 | 53 ab | 20 | 3 | 11 bcd | 14 bcde | 76 abc | 4 |
| 8. Glypper | 0.2 | 0 | 223 abc | 109 | 166 abcd | 112 | 47 d | 15 | 4 | 19 a | 15 abcde | 66 e | 4 |
| 9. Spotlight + Beloukha | 0.1 | 0 + 0.1 | 231 abc | 138 | 185 ab | 125 | 64 a | 15 | 2 | 7 e | 14 bcde | 80 a | 4 |
| 10. Glypper + Beloukha | 0.2 | 0 | 263 a | 116 | 190 ab | 128 | 57 abc | 13 | 4 | 15 ab | 11 e | 74 bcd | 4 |
| 11. Flurostar | 0.2 | 0 | 150 c | 107 | 129 cd | 87 | 54 bcd | 14 | 4 | 11 bcd | 19 a | 73 cd | 4 |
| 12. Saltex, 22.5% | 80 | 80 | 238 ab | 136 | 187 ab | 126 | 57 abc | 12 | 3 | 12 bc | 16 abc | 72 d | 4 |
| 13. Saltex, 22.5% | 0 | 80 | 178 bc | 106 | 142 bcd | 96 | 59 abc | 16 | 2 | 9 | 16 abc | 76 abcd | 4 |
| 14. No desiccation (unsprayed control) | 0 | 0 | 209 abc | 88 | 148 bcd | 100 | 56 abcd | 21 | 3 | 7 e | 13 bcde | 80 a | 4 |

*p-value* 0.03 >.05 0.02 >.05 >.05 >.05 <.01 0.02 <.01 <.01 <.01 <.01 <.01 <.01 <.01 <.01 <.01

aGermination capacity included ungerminated fresh seeds and up to 40% hard seeds.
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 yield 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 considered for use in clover seed production.

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