**Supplementary Materials**

**Supplementary Table 1.** Average temperature at the Flakkebjerg Research Centre, Denmark, during the months of April to August in 2019 (EXP2019) and 2020 (EXP2020) compared with the 10-year average, from 2009 to 2018. Standard errors are presented in parentheses.

|  |  |
| --- | --- |
| Month | Average temperature |
| EXP2019 |  | EXP2020 |  | 10-year average |
| °C |
| April | 8.29 | (±0.19) |  | 8.16 | (±0.14) |  |  7.851 | (±0.047) |
| May | 10.48 | (±0.15) |  | 10.72 | (±0.14) |  |  12.108 | (±0.054) |
| June | 17.12 | (±0.15) |  | 16.59 | (±0.16) |  |  14.809 | (±0.045) |
| July | 17.34 | (±0.18) |  | 15.60 | (±0.12) |  |  17.681 | (±0.049) |
| August | 18.10 | (±0.14) |   | 19.00 | (±0.18) |   |  17.141 | (±0.041) |

**Supplementary Table 2.** Total precipitation at the Flakkebjerg Research Centre, Denmark, during the months of April to August in 2019 (EXP2019) and 2020 (EXP2020) compared with the 10-year average, from 2009 to 2018. Standard errors are presented in parentheses.

|  |  |
| --- | --- |
| Month | Total precipitation |
| EXP2019 |  | EXP2020 |  | 10-year average |
| mm |
| April | 13.4 |  | 18.1 |  |  27.1 | (±4.2) |
| May | 48.7 |  | 14.7 |  |  39.3 | (±6.1) |
| June | 59.1 |  | 48.5 |  |  68.6 | (±15.8) |
| July | 42.5 |  | 60.6 |  |  54.1 | (±9.4) |
| August | 55.3 |   | 55.3 |   |  66.9 | (±12.8) |

**Supplementary Table 3.** Target and achieved spring barley (*Hordeum vulgare*) crop densitiesin2019 (EXP2019) and 2020 (EXP2020) across treatment plots possessing row spacings of 15 cm (RS15) and 20 cm (RS20) and target densities of 200 (CD200), 300 (CD300), 400 (CD400), and 500 (CD500) plants m-2. Both full-width and intra-row crop densities are presented. Full-width densities are calculated at field-scale, spanning across both the inter- and intra-row zones. Intra-row densities are defined as 7 cm wide bands centered on crop rows, which do not receive inter-row hoeing. Standard errors are presented in parentheses.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   | Treatment | Full-width crop density |   | Intra-row crop density |
| Experiment | Target |  | Achieved |  | Target |  | Achieved |
|   | no. m−2 |
| EXP2019 | RS15 | CD200 | 200 |  | 215 | (±7) |  |  429 |  |  461 | (±15) |
|  |  | CD300 | 300 |  | 298 | (±9) |  |  643 |  |  639 | (±19) |
|  |  | CD400 | 400 |  | 402 | (±13) |  |  857 |  |  861 | (±28) |
|  |  | CD500 | 500 |  | 516 | (±19) |  | 1071 |  | 1105 | (±41) |
|  | RS20 | CD200 | 200 |  | 235 | (±10) |  |  571 |  |  671 | (±28) |
|  |  | CD300 | 300 |  | 339 | (±10) |  |  857 |  |  970 | (±29) |
|  |  | CD400 | 400 |  | 438 | (±14) |  | 1143 |  | 1253 | (±40) |
|  |  | CD500 | 500 |  | 558 | (±18) |  | 1429 |  | 1593 | (±52) |
| EXP2020 | RS15 | CD200 | 200 |  | 160 | (±8) |  |  429 |  |  343 | (±18) |
|  |  | CD300 | 300 |  | 244 | (±7) |  |  643 |  |  523 | (±16) |
|  |  | CD400 | 400 |  | 298 | (±17) |  |  857 |  |  639 | (±36) |
|  |  | CD500 | 500 |  | 369 | (±26) |  | 1071 |  |  791 | (±55) |
|  | RS20 | CD200 | 200 |  | 158 | (±5) |  |  571 |  |  451 | (±13) |
|  |  | CD300 | 300 |  | 251 | (±10) |  |  857 |  |  717 | (±29) |
|  |  | CD400 | 400 |  | 329 | (±18) |  | 1143 |  |  941 | (±53) |
|   |   | CD500 | 500 |   | 389 | (±16) |   | 1429 |   | 1112 | (±47) |

**Supplementary Table 4.** Estimates of parameters *a* and *b* for spring barley crop (*Hordeum vulgare*) biomass from Equation (1). Parameter estimates of the reduced model are shown for experiments performed in 2020 (EXP2020) among plots sown to 15 cm (RS15) and 20 cm (RS20) row spacings, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow). All plots received inter-row hoeing.

|  |  |  |
| --- | --- | --- |
| Experiment | Treatment | Crop biomass |
| *a* |  | *b* |
| g m-2 |  | g m-2 plant-1 |
| EXP2020 | RS15 | WMTherbicide | 592 |  | 0.3553 |
|  | RS15 | WMTweedy | 558 |  | 0.3553 |
|  | RS15 | WMTtineharrow | 558 |  | 0.3553 |
|  | RS20 | WMTherbicide | 592 |  | 0.3553 |
|  | RS20 | WMTweedy | 558 |  | 0.3553 |
|   | RS20 | WMTtineharrow | 558 |   | 0.3553 |

**Supplementary Table 5.** Estimates of parameters *a* and *b* for spring barley (*Hordeum vulgare*) grain protein from Equation (1). Parameter estimates of the reduced model are shown for experiments performed in 2019 (EXP2019) among plots sown to 15 cm (RS15) and 20 cm (RS20) row spacings, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow). All plots received inter-row hoeing.

|  |  |  |
| --- | --- | --- |
| Experiment | Treatment | Grain protein |
| *a* |  | *b* |
| % |  | % plant-1 |
| EXP2019 | RS15 | WMTherbicide | 10.45 |  | -0.001249 |
|  | RS15 | WMTweedy | 10.45 |  | -0.001249 |
|  | RS15 | WMTtineharrow | 10.45 |  | -0.001249 |
|  | RS20 | WMTherbicide | 10.45 |  | -0.001249 |
|  | RS20 | WMTweedy | 10.45 |  | -0.001249 |
|   | RS20 | WMTtineharrow | 10.45 |   | -0.001249 |

**Supplementary Table 6.** Estimates of parameters *a* and *b* for spring barley (*Hordeum vulgare*) grain bulk density from Equation (1). Parameter estimates of the reduced model are shown for experiments performed in 2019 (EXP2019) and 2020 (EXP2020) among plots sown to 15 cm (RS15) and 20 cm (RS20) row spacings, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow). All plots received inter-row hoeing.

|  |  |  |
| --- | --- | --- |
| Experiment | Treatment | Grain bulk density |
| *a* |  | *b* |
| kg hL-1 |  | kg hL-1 plant-1 |
| EXP2019 | RS15 | WMTherbicide | 64.09 |  | -0.006060 |
|  | RS15 | WMTweedy | 64.09 |  | -0.006060 |
|  | RS15 | WMTtineharrow | 64.09 |  | -0.006060 |
|  | RS20 | WMTherbicide | 64.09 |  | -0.006060 |
|  | RS20 | WMTweedy | 64.09 |  | -0.006060 |
|   | RS20 | WMTtineharrow | 64.09 |   | -0.006060 |
| EXP2020 | RS15 | WMTherbicide | 73.23 |  | -0.005408 |
|  | RS15 | WMTweedy | 72.52 |  | -0.005408 |
|  | RS15 | WMTtineharrow | 72.52 |  | -0.005408 |
|  | RS20 | WMTherbicide | 73.23 |  | -0.005408 |
|  | RS20 | WMTweedy | 72.52 |  | -0.005408 |
|   | RS20 | WMTtineharrow | 72.52 |   | -0.005408 |

Supplementary Figure 1. The relationship between crop biomass (g m-2; *Hordeum vulgare*) and crop density (plants m-2). Observed values represent means of the reduced model for two row spacings, 15 cm (RS15) and 20 cm (RS20), and three weed management treatments, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow) in 2020 (EXP2020). All plots received inter-row hoeing.

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Supplementary Figure 2. The relationship between grain protein (%; *Hordeum vulgare*) and crop density (plants m-2). Observed values represent means of the reduced model for two row spacings, 15 cm (RS15) and 20 cm (RS20), and three weed management treatments, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow) in 2019 (a; EXP2019) and 2020 (b; EXP2020). All plots received inter-row hoeing.



Supplementary Figure 3. The relationship between grain bulk density (kg hL-1; *Hordeum vulgare*) and crop density (plants m-2). Observed values represent means of the reduced model for two row spacings, 15 cm (RS15) and 20 cm (RS20), and three weed management treatments, receiving treatment with herbicide (WMTherbicide), no additional weed management treatment (WMTweedy), and pre-emergence tine harrowing (WMTtineharrow) in 2019 (a; EXP2019) and 2020 (b; EXP2020). All plots received inter-row hoeing.

