**Table S1**. **Number of farmer’s field at each Agro-ecological zones and soil types**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trial | Number of farmers’ fields | | | | |
| AEZ | | | Soil Type | |
| SH3 | SM3 | SM4 | Cambisols | Vertisols |
| N | 14 | 3 | 5 | 20 | 2 |
| P | 13 | 3 | 4 | 19 | 2 |
| K | 12 | 4 | 4 | 18 | 2 |
| S | 13 | 3 | 5 | 18 | 2 |
| **Total** | **83** | | | **83** | |

AEZ=Agro-ecological zones, SH3= tepid sub-humid mid-highlands (Sinana district), SM3= tepid sub-moist mid-highlands (Basona Werana districts, Gudoberet kebele), SM4= cool sub-moist mid-highland (Goshebado kebele of Basona Werana district and Alaje districts)

# Supplementary Table S2. Model comparison for N rate using AIC and BIC

|  |  |  |
| --- | --- | --- |
| Model | AICc | BIC |
|  | 6416.6 | 6417.5 |
|  | 6326.9 | 6327.8 |
|  | 6293.3 | 6294.2 |
|  | 6040.7 | 6041.6 |
|  | 6040.7 | 6041.6 |

The interaction effect could not be estimated

**Supplementary Table S3. Significance of fixed effects**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Nutrient | Effect | Num DF | Den DF | F value | P > F |
| N rate | AEZ | 2 | 7.74 | 1.01 | 0.4064 |
|  | Soil | 1 | 7.75 | 0.39 | 0.5493 |
|  | Rep | 2 | 362 | 0.03 | 0.9721 |
|  | Rate | 5 | 362 | 10.42 | <.0001 |
|  | AEZ\*Rate | 10 | 362 | 13.62 | <.0001 |
|  | Soil\*Rate | 5 | 362 | 1.97 | 0.0825 |
| P rate | AEZ | 2 | 8.65 | 1.91 | 0.2053 |
|  | Soil | 1 | 8.69 | 0 | 0.9676 |
|  | Rep | 2 | 325 | 0.52 | 0.5969 |
|  | Rate | 5 | 325 | 0.64 | 0.6682 |
|  | AEZ\*Rate | 10 | 325 | 2.91 | 0.0017 |
|  | Soil\*Rate | 5 | 325 | 2.98 | 0.0121 |
| K rate | AEZ | 2 | 21.8 | 6.69 | 0.0054 |
|  | Soil | 1 | 9.05 | 1.3 | 0.2841 |
|  | Rep | 2 | 325 | 2.03 | 0.1335 |
|  | Rate | 5 | 325 | 0.04 | 0.9991 |
|  | AEZ\*Rate | 10 | 325 | 0.31 | 0.9773 |
|  | Soil\*Rate | 5 | 325 | 0.19 | 0.9651 |
| S rate | AEZ | 2 | 15 | 4.78 | 0.0249 |
|  | Soil | 1 | 8.46 | 0.24 | 0.6358 |
|  | Rep | 2 | 339 | 2.83 | 0.0603 |
|  | Rate | 5 | 340 | 0.12 | 0.9874 |
|  | AEZ\*Rate | 10 | 340 | 0.75 | 0.6747 |
|  | Soil\*Rate | 5 | 339 | 0.46 | 0.8025 |

AEZ=Agro-ecological zones, Rep=Replication, Rate=Nutrient rate

**Supplementary Table S4. Covariance parameter estimates**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Cov Parm | Subject | Estimate | Value | Pr Z | ICC§ |
| Nrate | Intercept | Location | 1020737 | 1.94 | 0.0259 | 65.1 |
|  | Residual |  | 546624 | 13.45 | <.0001 |  |
| Prate | Intercept | Location | 717314 | 2.03 | 0.021 | 52.6 |
|  | Residual |  | 645834 | 12.75 | <.0001 |  |
| Krate | Intercept | Location | 842636 | 2.05 | 0.0202 | 56.3 |
|  | Residual |  | 653411 | 12.75 | <.0001 |  |
| S rate | Intercept | Location | 1152347 | 1.88 | 0.0298 | 56.4 |
|  | Residual |  | 889467 | 13.02 | <.0001 |  |

§ ICC is the intraclass correlation.

**Table S5.** **The main effect of N and P rate on grain yield, total biomass, and rainwater productivity across agro-ecology zone (AEZ) and soil type in Ethiopia**

**Response to N rate**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Grain yield (kg ha-1) | | | | | |
| N rate | AEZ | | | Soil type | |
| (kg ha-1) | SH3 | SM3 | SM4 | Cambisols | Vertisols |
| 0 | 1855 (282–3427)a | 1065 (-1412–3543) | 2203 (753–3653) | 2060 (1425–2694) | 2361 (274–4448) |
| 46 | 2268 (695–3841) | 1690 (-787–4168) | 3014 (1564–4464) | 2604 (1969–3239) | 2777 (690–4864) |
| 92 | 2255 (683–3828) | 2999 (521–5477) | 3551 (2101–5001) | 2911 (2277–3546) | 2916 (829–5003) |
| 138 | 2281 (709–3854) | 3321 (843–5799) | 3767 (2317–5218) | 3002 (2367–3637) | 3305 (1218–5392) |
| 184 | 2193 (620–3765) | 3708 (1230–6186) | 4416 (2966–5866) | 3112 (2477–3747) | 3750 (1663–5836) |
| 230 | 2241 (669–3814) | 4358 (1880–6836) | 4719 (3269–6169) | 3273 (2638–3907) | 4111 (2024–6198) |
| Biomass yield (kg ha-1) | | | | | |
| 0 | 8889 (2525–15253) | 3420 (-6585–13426) | 6487 (661–12313) | 7544 (5200–9889) | 8402 (669–16136) |
| 46 | 10516 (4152–16879) | 4873 (-5132–14878) | 8165 (2339–13991) | 9247 (6902–11592) | 9138 (1405–16872) |
| 92 | 11449 (5085–17812) | 7177 (-2828–17182) | 9327 (3501–15153) | 10542 (8197–12886) | 9083 (1349–16816) |
| 138 | 11088 (4724–17451) | 8774 (-1231–18780) | 10228 (4402–16053) | 10615 (8270–12959) | 10472 (2738–18205) |
| 184 | 11104 (4740–17467) | 9356 (-649–19362) | 11447 (5621–17272) | 10996 (8651–13340) | 10694 (2960–18427) |
| 230 | 11723 (5359–18086) | 10200 (194–20205) | 12270 (6444–18095) | 11656 (9311–14000) | 11750 (4016–19483) |
| Rainwater productivity (kg mm-1) | | | | | |
| 0 | 3.9 (2.8–4.9) | 1.8 (-0.9–4.6) | 2.7 (-0.1–5.5) | 3.3 (2.3–4.2) | 4.2 (1.2–7.2) |
| 46 | 4.5 (3.5–5.6) | 2.6 (-0.2–5.4) | 4 (1.2–6.7) | 4.0 (3.1–5) | 4.9 (1.9–8) |
| 92 | 4.5 (3.5–5.5) | 4.2 (1.4–7) | 4.9 (2.1–7.7) | 4.4 (3.5–5.3) | 5.2 (2.1–8.2) |
| 138 | 4.6 (3.5–5.6) | 4.6 (1.8–7.4) | 5.1 (2.3–7.9) | 4.5 (3.6–5.4) | 5.9 (2.8–8.9) |
| 184 | 4.4 (3.4–5.4) | 5.1 (2.3–7.9) | 6 (3.2–8.8) | 4.6 (3.7–5.6) | 6.7 (3.6–9.7) |
| 230 | 4.5 (3.5–5.5) | 5.9 (3.1–8.7) | 6.2 (3.4–9) | 4.8 (3.9–5.8) | 7.3 (4.3–10.3) |

Response to P

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Grain yield (kg ha-1) | | | | | |
| P rate | AEZ | | | Soil type | |
| (kg ha-1) | SH3 | SM3 | SM4 | Cambisols | Vertisols |
| 0 | 2295 (971–3619)b | 1915 (-193–4024) | 3562 (2301–4822) | 2323 (1749–2898) | 3916 (2042–5790) |
| 10 | 2423 (1099–3747) | 2618 (509–4727) | 3853 (2593–5114) | 2567 (1992–3141) | 4194 (2320–6068) |
| 20 | 2529 (1204–3853) | 2884 (775–4993) | 4301 (3040–5561) | 2775 (2200–3349) | 4305 (2431–6179) |
| 30 | 2519 (1195–3844) | 2776 (667–4884) | 4191 (2930–5451) | 2722 (2148–3297) | 4333 (2459–6207) |
| 40 | 2619 (1295–3943) | 2833 (724–4941) | 4811 (3550–6071) | 2926 (2352–3501) | 4472 (2598–6346) |
| 50 | 2599 (1274–3923) | 3292 (1184–5401) | 4821 (3560–6081) | 3024 (2450–3599) | 4166 (2292–6040) |
| Biomass yield (kg ha-1) | | | | | |
| 0 | 9355 (2805–15906) | 3823 (-6556–14204) | 8310 (2250–14369) | 9004 (6608–11400) | 8805 (578–17032) |
| 10 | 10099 (3548–16649) | 5176 (-5203–15557) | 9045 (2986–15105) | 9816 (7420–12211) | 9833 (1606–18060) |
| 20 | 10193 (3642–16743) | 5817 (-4563–16197) | 10228 (4168–16287) | 10198 (7802–12593) | 10333 (2105–18560) |
| 30 | 10443 (3892–16993) | 5730 (-4649–16111) | 10503 (4443–16562) | 10459 (8063–12854) | 10028 (1800–18255) |
| 40 | 10595 (4044–17145) | 5761 (-4618–16142) | 11409 (5349–17468) | 10757 (8361–13152) | 10195 (1967–18422) |
| 50 | 10796 (4245–17346) | 6844 (-3536–17224) | 11731 (5671–17790) | 11213 (8817–13608) | 9666 (1439–17893) |
| Rainwater productivity (kg mm-1) | | | | | |
| 0 | 3.7 (2.7–4.6) | 2.4 (-0.2–5) | 3.8 (1.1–6.4) | 3.6 (2.8–4.4) | 6.9 (4.3–9.5) |
| 10 | 3.9 (2.9–4.9) | 3.2 (0.6–5.8) | 4.1 (1.5–6.8) | 3.9 (3.1–4.7) | 7.4 (4.8–10) |
| 20 | 4.1 (3.1–5.0) | 3.6 (1–6.1) | 5.1 (2.4–7.7) | 4.2 (3.4–5) | 7.6 (5–10.2) |
| 30 | 4.1 (3.1–5) | 3.4 (0.8–6) | 4.8 (2.1–7.4) | 4.1 (3.3–4.9) | 7.7 (5.1–10.3) |
| 40 | 4.2 (3.2–5.2) | 3.5 (0.–6.1) | 6.1 (3.4–8.7) | 4.4 (3.6–5.2) | 8 (5.3–10.5) |
| 50 | 4.2 (3.2–5.1) | 4 (1.5–6.6) | 6.4 (3.8–9.1) | 4.5 (3.7–5.3) | 7.4 (4.8–10) |

b Numbers in brackets are confidence intervals.

AEZ=Agro-ecological zones, SH3= tepid sub-humid mid-highlands (Sinana district), SM3= tepid sub-moist mid-highlands (Basona Werana districts, Gudoberet kebele), SM4= cool sub-moist mid-highland (Goshebado kebele of Basona Werana district and Alajedistricts)

**Table S6.** **The main effect of K and S rates on grain yield, total biomass, and rainwater productivity across agro-ecology zone (AEZ) and soil type in Ethiopia**

**Response to K**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | AEZ | | | Soil type | | |
|  | Grain yield (kg ha-1) |  |  |  | |
| K rate(kg ha-1) | SH3 | SM3 | SM4 | Cambisols | Vertisols | |
| 0 | 1587 (287–2887)d | 3343 (2119–4568) | 4065 (2869–5262) | 2677 (1915–3439) | 3564 (1168–5960) | |
| 18 | 1683 (383–2983) | 3466 (2241–4691) | 4159 (2962–5356) | 2797 (2035–3559) | 3495 (1099–5891) | |
| 36 | 1610 (310–2910) | 3521 (2297–4746) | 4152 (2955–5349) | 2768 (2005–3530) | 3418 (1022–5814) | |
| 54 | 1670 (370–2970) | 3454 (2230–4679) | 3737 (2540–4934) | 2729 (1966–3491) | 3163 (767–5559) | |
| 72 | 1678 (378–2978) | 3419 (2195–4644) | 4212 (3016–5409) | 2803 (2040–3565) | 3431 (1035–5827) | |
| 90 | 1748 (448–3048) | 3510 (2285–4735) | 3881 (2684–5078) | 2818 (2056–3581) | 3222 (826–5618) | |
| Biomass yield (kg ha-1) | | | | | | | |
| 0 | 9013 (2312–15714) | 8061 (2052–14070) | 10064 (4097–16030) | 10415 (7628–13201) | | 8638 (-556–17834) | | |
| 18 | 9443 (2743–16144) | 8162 (2153–14172) | 10194 (4227–16160) | 10741 (7954–13527) | | 8750 (-445–17945) | | |
| 36 | 9059 (2358–15760) | 8114 (2105–14124) | 10146 (4179–16112) | 10433 (7646–13219) | | 9027 (-167–18223) | | |
| 54 | 9059 (2358–15760) | 7931 (1921–13940) | 9791 (3825–15758) | 10381 (7594–13167) | | 8416 (-778–17612) | | |
| 72 | 9555 (2854–16255) | 8181 (2172–14190) | 10397 (4430–16363) | 10867 (8080–13653) | | 8722 (-473–17917) | | |
| 90 | 9869 (3169–16570) | 8256 (2247–14266) | 10132 (4165–16098) | 11038 (8251–13824) | | 8694 (-501–17889) | | |
| Rainwater productivity (kg mm-1) | | | | | | | |
| 0 | 3.6 (2.4–4.6) | 4.9 (2.9–6.9) | 5.4 (3.2–7.6) | 4 (3–5) | 6.3 (3.2–9.4) | |
| 18 | 3.7 (2.6–4.8) | 5 (3–7.1) | 5.7 (3.4–7.8) | 4.2 (3.2–5.1) | 6.2 (3.1–9.3) | |
| 36 | 3.6 (2.5–4.7) | 5.1 (3.1–7.1) | 5.7 (3.5–7.9) | 4.1 (3.1–51) | 6.1 (3–9.1) | |
| 54 | 3.7 (2.6–4.8) | 5 (3–7.1) | 5.1 (2.9–7.2) | 4.1 (3.1–5.1) | 5.6 (2.6–8.7) | |
| 72 | 3.7 (2.6–4.8) | 5 (3–7) | 5.9 (3.7–8) | 4.2 (3.2–5.1) | 6.1 (3–9.2) | |
| 90 | 3.8 (2.7–4.9) | 5.1 (3.1–7) | 5.3 (3.1–7.5) | 4.2 (3.–5.2) | 5.7 (2.7–8.8) | |

Response to S

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Grain yield (kg ha-1) | | | | | | |
| S rate(kg ha-1) |  |  |  |  |  |
| 0 | 2699 (1132–4267)c | 5524 (3745–7302) | 3548 (2109–4987) | 2628 (1846–3409) | 4249 (1682–6817) |
| 10 | 2673 (1108–4238) | 5536 (3646–7426) | 4059 (2625–5493) | 2726 (1945–3508) | 4277 (1710–6845) |
| 20 | 2644 (1079–4210) | 5837 (3947–7727) | 4055 (2621–5489) | 2745 (1963–3526) | 4353 (1785–6920) |
| 30 | 2663 (1097–4228) | 5571 (3682–7461) | 4156 (2723–5590) | 2718 (1937–3500) | 4583 (2015–7150) |
| 40 | 2629 (1063–4196) | 5447 (3557–7336) | 4309 (2875–5742) | 2724 (1943–3506) | 4444 (1877–7011) |
| 50 | 2772 (1207–4338) | 5821 (3931–7711) | 4027 (2593–5460) | 2828 (2046–3609) | 4305 (1738–6872) |
| Biomass yield (kg ha-1) | | | | | | |
| 0 | 11569 (5038–18099) | 12142 (5551–18732) | 8865 (3016–14715) | 10069 (7477–12660) | 11250 (2720–19779) |
| 10 | 12207 (5678–18735) | 12171 (5322–19019) | 10216 (4376–16055) | 10848 (8260–13435) | 10778 (2248–19307) |
| 20 | 11733 (5204–18261) | 13080 (6231–19928) | 10410 (4570–16249) | 10648 (8060–13235) | 11444 (2914–19973) |
| 30 | 12164 (5635–18692) | 12555 (5706–19403) | 10220 (4380–16059) | 10781 (8193–13368) | 11722 (3192–20251) |
| 40 | 11492 (4961–18022) | 12503 (5654–19351) | 10546 (4706–16385) | 10490 (7901–13078) | 10917 (2387–19446) |
| 50 | 12361 (5832–18889) | 12956 (6107–19804) | 10025 (4185–15864) | 10974 (8386–13561) | 11278 (2748–19807) |
| Rainwater productivity (kg mm-1) | | | | | | |
| 0 | 3.9 (2.9–5) | 6.2 (3.8–8.6) | 3.7 (1.1–6.2) | 4 (3.1–5) | 7.6 (4.3–10.8) |
| 10 | 3.9 (2.8–5) | 6.2 (3.6–8.7) | 4.7 (2.1–7.2) | 4.1 (3.1–5.1) | 7.6 (4.4–10.8) |
| 20 | 3.8 (2.7–5) | 6.6 (4.0–9.1) | 4.6 (2.1–7.1) | 4.1 (3.1–5.1) | 7.7 (4.5–10.8) |
| 30 | 3.9 (2.8–5) | 6 (3.7–8.8) | 4.6 (2.1–7.2) | 4.1 (3.1–5.1) | 8 (4.9–11.4) |
| 40 | 3.8 (2.7–4.9) | 6.1 (3.5–8.6) | 5 (2.5–7.6) | 4.1 (3.1–5.1) | 7.9 (4.7–11.1) |
| 50 | 4 (2.9–5.1) | 6.5 (4–9.1) | 4.6 (2.1–7.1) | 4.2 (3.2–5.2) | 7.7 (4.4–10.9) |

c Numbers in brackets are confidence intervals.

AEZ=Agro-ecological zones, SH3= tepid sub-humid mid-highlands (Sinana district), SM3= tepid sub-moist mid-highlands (Basona Werana districts, Gudoberet kebele), SM4= cool sub-moist mid-highland (Goshebado kebele of Basona Werana district and Alaje districts)