SOIL HEALTH IMPLICATION STATEMENTS

Malawi

Scenario quadrant: High climate risk (RCP8.5) / effective agricultural policies (HT)

- Increasing soil carbon stock will help to improve the soil's capacity to support crop and pasture production.
- Maintaining climate-smart agricultural practices such as conservation agriculture in all areas where this is suitable will help to minimize soil carbon loss and enhance the resilience of the agricultural system to climate shocks
- Monitoring the quality of irrigation water and ensuring good irrigation practices will minimize salinization and other soil chemical degradation processes which are known to reduce agricultural productivity
- To ensure climate-smartness, irrigation systems should be powered by renewable energy sources.
- It will be important to manage fertilizer application to maximize nutrient use efficiency, to avoid high N_2O emissions under high crop residue and soil carbon conditions.

These implication statements are based on the following calibrated statements (CS):

- At the same time soil organic carbon stocks increase (+59%) due to higher carbon returns to the soil *(Emissions and Soils CS)*.
- The mean percentage change to irrigation water with RCP8.5, scenario ht is 1130% (range across climate models 817 to 1668%; 1/18 climate models are outliers). This becomes mean 1098%, range 817 to 1584% after removing the upper limit outliers *(Irrigation CS3)*.

Scenario quadrant: High climate risk (RCP8.5) / ineffective agricultural policies (LT)

- Intensification of agricultural production on shrinking agricultural land will accelerate soil erosion and carbon loss, which will exacerbate soil degradation in the forms of fertility decline and weakened soil structure, leading to significant reduction in crop and pasture production.
- Climate-smart agricultural practices such as conservation agriculture and integrated soil fertility management are promising strategies for increasing agricultural productivity and enhancing soil carbon sequestration when implemented correctly and where they are suitable.
- Climate-smart agricultural practices will help to conserve soil water, reduce greenhouse gas emissions from agricultural lands and contribute to climate change mitigation.

These implication statements are based on:

- A scenario characterised by a 10% reduction in all arable and livestock pasture areas 10% reduction in irrigated areas *(Scenario Description)*

- Increasing the intensity of rainfall is likely to increase the amount of annual soil erosion, relative to the present day. Agricultural areas at high risk of soil erosion may more than double *(Soil Erosion CS).*
- National greenhouse gas (GHG) emissions under the LT scenario are -31% compared to the year 2000. At the same time soil organic carbon stocks changed by -15%. Overall, net GHG emissions changed by +74% in total and emission intensities (GHG/unit product) changed by +103% *(Emissions and Soils CS)*.
- The mean percentage change to crop production with RCP8.5, scenario lt is -14% (range across climate models -26 to -7%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to irrigation water with RCP8.5, scenario lt is 5% (range across climate models -17 to 38%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- A downward trend in yields, coupled with increasing yield variability in the case of soybean and potato, contributes to an increase of approximately 2-3 times the number of years of yield shock for maize and groundnut and ~6 times more yield shocks for potato. Soybean yields do not show a downward trend and show an increase of only 0-1 times more yield shocks. Medium Confidence *(Yield Shocks CS)*.

Scenario quadrant: Low climate risk (RCP2.6) / effective agricultural policies (HT)

- Effective soil fertility management such as targeted fertilizer application will help to minimize soil fertility decline and sustain agricultural productivity.
- Integrated crop-livestock production systems where livestock manure is properly processed and applied to soils for crop and pasture production will help to reduce the cost of production (e.g. cost of fertilizers) and sustain the benefits of improved soil health such as increases in both crop and livestock production.

These implication statements are based on the following CS:

- The mean percentage change to crop production with RCP2.6, scenario ht is 728% (range across climate models 676 to 759%; 1/18 climate models are outliers). This becomes mean 731%, range 676 to 759% after removing the lower limit outliers *(Food Production CS1)*.
- The mean percentage change to livestock meat production with RCP2.6, scenario ht is 151% (range across climate models 130 to 160%; 1/18 climate models are outliers). This becomes mean 152%, range 137 to 160% after removing the lower limit outliers *(Food Production CS2)*.
- The mean percentage change to livestock dairy production with RCP2.6, scenario ht is 237% (range across climate models 227 to 249%; 3/18 climate models are outliers). This becomes mean 237%, range 230 to 245% after removing both upper and lower limit outliers *(Food Production CS2)*.

Scenario quadrant: Low climate risk (RCP2.6) / ineffective agricultural policies (LT)

- Proactive soil fertility management practices such as targeted fertilizer application with enhanced nutrient use efficiency will help to minimize decline in crop yield
- Without irrigation, there will be need for soil water conservation practices such as organic mulching to minimize soil water loss which affects crop production

These implication statements are based on the following CS:

- The mean percentage change to crop production with RCP2.6, scenario lt is -1% (range across climate models -16 to 11%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to irrigation water with RCP2.6, scenario lt is 13% (range across climate models -20 to 33%; 1/18 climate models are outliers). This becomes mean 15%, range -17 to 33% after removing the lower limit outliers *(Irrigation CS3)*.
- A downward trend in yields, coupled with increasing yield variability in the case of soybean and potato, result in approximately double the number of years of yield shock. Soybean shows signs of being more resilient to extreme weather, with fewer shocks than the other three crops. Medium Confidence *(Yield Shocks CS)*.

South Africa

Scenario quadrant: High climate risk (RCP8.5) / high land reform (HT)

- Efficient irrigation practices to ensure that salts are not accumulated in the soil and soil nutrients are not leached will help to increase crop yields
- Practices that improve soil carbon build-up such as leaving crop residues on the field after harvest will help to increase the resilience of crops to climate shocks

These implication statements are based on: a scenario characterised by a 10% fall in arable crop land and the following CS:

- At the same time soil organic carbon stocks changed by -17% *(Emissions and Soils CS)*.
- The mean percentage change to irrigation water with RCP8.5, scenario ht is 67% (range across climate models 42 to 97%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- Yield shock rates largely decrease due to the applied technology trend to yields and irrigation. If not assuming this technology trend increase to mean yields, and with no benefits from irrigation in future, yield shocks typically increase. Medium Confidence *(Yield Shocks CS)*.

Scenario quadrant: High climate risk (RCP8.5) / low land reform (LT)

- Expanding arable land may initially lead to yield increase as fertile lands are brought into cultivation. Without proper soil fertility management, crop yield will start to decline as inherent soil nutrients are depleted

- Ensuring proper irrigation practices including the use of high-quality water, minimizing excess leaching and waterlogging of soils will be key in ensuring that yield and climate change mitigation benefits of expanding irrigation to all arable lands are achieved and maintained

These implication statements are based on:

- A scenario characterised by a 10% increase in arable crop land, and a 10% decrease in livestock pasture area *(Scenario Description)*.
- National greenhouse gas (GHG) emissions under the LT scenario are +51% compared to the year 2000 based on the increase in crop production. At the same time soil organic carbon stocks changed by -13% *(Emissions and Soils CS).*
- The mean percentage change to crop production with RCP8.5, scenario lt is 178% (range across climate models 150 to 192%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to irrigation water with RCP8.5, scenario lt is 84% (range across climate models 65 to 115%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- Yield shock rates largely decrease due to the applied technology trend to yields and irrigation. If not assuming this technology trend increase to mean yields, and with no benefits from irrigation in future, yield shocks typically increase. Medium Confidence *(Yield Shocks CS)*.

Scenario quadrant: Low climate risk (RCP2.6) / high land reform (HT)

- Greater soil health benefits of crop diversification away from maize will be achieved if legumes are intercropped or rotated with maize rather than growing each crop in monocropping systems.
- With increasing livestock production, proper management of livestock manure including its use as fertilizer will help to sustain gains in crop yield.

These implication statements are based on:

- A scenario where crop diversity increases slightly with maize being the main crop, but other crop areas expand by 10% at the expense of maize area *(Scenario Description)*.
- The mean percentage change to crop production with RCP2.6, scenario ht is 101% (range across climate models 81 to 116%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to livestock meat production with RCP2.6, scenario ht is 122% (range across climate models 103 to 135%; 0/18 climate models are outliers) *(Food Production CS2)*.

- The mean percentage change to livestock dairy production with RCP2.6, scenario ht is 113% (range across climate models 95 to 126%; 0/18 climate models are outliers) *(Food Production CS2)*.

Scenario quadrant: Low climate risk (RCP2.6) / low land reform (LT)

- Integrated soil fertility management including the addition of properly processed livestock manure to soil and maize-legume intercropping or rotation will help to maintain and/or increase crop and pasture yields.

These implication statements are based on:

- National greenhouse gas (GHG) emissions under the LT scenario are +52% compared to the year 2000 based on the increase in crop and livestock production. At the same time soil organic carbon stocks changed by -1% *(Emissions and Soils CS)*
- Without adaptation, climate change results in mean yields decreasing in this scenario. The impacts of climate change on maize, soybean and potato still result in small yield losses (< 5%) even with autonomous adaptation, with little change to groundnut yields projected. High Confidence *(Climate Impacts CS)*.
- The mean percentage change to crop production with RCP2.6, scenario lt is 117% (range across climate models 94 to 136%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to livestock meat production with RCP2.6, scenario lt is 122% (range across climate models 98 to 136%; 0/18 climate models are outliers) *(Food Production CS2)*.
- The mean percentage change to livestock dairy production with RCP2.6, scenario lt is 115% (range across climate models 91 to 129%; 0/18 climate models are outliers) *(Food Production CS2)*.

Tanzania

Scenario quadrant: High climate risk (RCP8.5) / high technology (HT)

- To increase the resilience of the agricultural lands to climate shocks, irrigation and the use of improved varieties need to be combined with other soil and water management practices such as terraces and contour barriers across slopes in the highlands that are prone to erosion
- Implementing conservation agriculture where suitable will help to maintain healthy soils for both crop and livestock production

These implication statements are based on:

- Increasing the intensity of rainfall is likely to increase the amount of annual soil erosion, relative to the present day. Agricultural areas at high risk of soil erosion may more than double *(Soil Erosion CS).*
- With adaptation of new varieties and irrigation, crop yields will most likely increase - by more than 10% in the case of maize and groundnut. Modest increases are likely for soybean, however potato could see decreasing yields. High Confidence *(Climate Impacts CS)*.
- The mean percentage change to irrigation water with RCP8.5, scenario ht is 608% (range across climate models 358 to 787%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- Effectively implemented irrigation and crop varietal improvements across the country result in significantly reduced yield shock rates. Medium Confidence *(Yield Shocks CS)*.

Scenario quadrant: High climate risk (RCP8.5) / low technology (LT)

- Relying on rainfed agriculture poses a challenge for soil health as increased frequency of extreme events such as droughts and soil erosion limits soil's capacity to perform functions such as supporting crop and pasture establishment and growth.
- Improved soil and water conservation practices such as construction of barriers across steep slopes in the highlands and maintaining soil surface cover will help to increase water and nutrient retention and availability to crops.

These implication statements are based on:

- Increasing the intensity of rainfall is likely to increase the amount of annual soil erosion, relative to the present day. Agricultural areas at high risk of soil erosion may more than double *(Soil Erosion CS).*
- The mean percentage change to irrigation water with RCP8.5, scenario lt is -100% (range across climate models -100 to -100%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- A downward trend in yields, coupled with increasing yield variability in the case of potato, contributes to, approximately, a doubling in the number of years of yield shocks for maize and groundnut and ~6 times more shocks for potato. Soybean yields show a smaller increase in shocks (30%, on average). Medium Confidence *(Yield shocks CS)*.

Scenario quadrant: Low climate risk (RCP2.6) / high technology (HT)

- Soil health benefits including build-up of soil carbon stock resulting from increased irrigation, crop diversification and use of improved crop varieties need to be sustained through effective irrigation practices that minimize waterlogging, soil nutrient leaching and salinization.

These implication statements are based on:

- National greenhouse gas (GHG) emissions under the HT scenario are +175% compared to the year 2000 based on the increase in crop and livestock production. At the same time soil organic carbon stocks changed by +56% due to higher carbon returns to the soil *(Emissions and Soils CS)*
- With adaptation of new varieties and irrigation, crop yields will most likely increase slightly - by just under 10% in the case of maize and groundnut, with more modest increases for soybean and little change for potato. High Confidence *(Climate Impacts CS).*
- The mean percentage change to irrigation water with RCP2.6, scenario ht is 607% (range across climate models 309 to 860%; 0/18 climate models are outliers) *(Irrigation CS3)*.
- Effectively implemented irrigation and crop varietal improvements across the country result in significantly reduced yield shock rates. Medium Confidence *(Yield Shocks CS)*.

Scenario quadrant: Low climate risk (RCP2.6) / low technology (LT)

- Expanding agricultural lands without proper soil fertility management will eventually lead to net decline in crop yields and soil carbon stocks despite any initial yield gains (and net biomass returns to soil) resulting from the utilization of inherent soil nutrient stocks
- Without irrigation, soil water conservation measures such as conservation agriculture is needed to ensure that soils store and supply sufficient water to crops

These implication statements are based on:

- A scenario characterised by a 58% increase in arable crop land and livestock pasture without increase to irrigated areas *(Scenario Description).*
- National greenhouse gas (GHG) emissions under the LT scenario are +45% compared to the year 2000. At the same time soil organic carbon stocks changed by +53% due to higher carbon returns to the soil *(Emissions and Soils CS)*.
- Without adaptation, climate change results in mean yields decreasing in this scenario. The impacts of climate change on C3 crop yields (soybean, potato and groundnut) are close to no change with autonomous adaptation, with some small gains for soybean projected. Maize yields are projected to fall in contrast by about 7%, even with autonomous adaptation. High Confidence *(Climate Impacts CS)*.
- The mean percentage change to crop production with RCP2.6, scenario lt is 65% (range across climate models 42 to 106%; 3/18 climate models are outliers). This becomes mean

64%, range 50 to 79% after removing both upper and lower limit outliers *(Food Production CS1)*.

- A downward trend in yields contributes to the ~50% increase in the number of years of yield shocks in maize and groundnut. Soybean shows signs of being more resilient to extreme weather, with only a small increase in yield shocks, and potato shows a much higher shock rate due to low baseline yield shocks and increasing variability. Medium Confidence *(Yield Shocks CS)*.

Zambia

Scenario quadrant: High climate risk (RCP8.5) / high market efficacy (HT)

- Crop yield gains resulting from increased irrigation and use of improved crop varieties can be sustained and even improved through other climate-smart land management practices such as integrated soil fertility management.
- Increasing soil carbon stock depends on the return of biomass to the soil, hence practices that encourage retention of crop residues in the field after harvest such as conservation agriculture will help to maintain healthy soils for increased crop and pasture production

These implication statements are based on:

- National greenhouse gas (GHG) emissions under the HT scenario are +183% compared to the year 2000 based on the increase in crop and livestock production. At the same time soil organic carbon stocks changed by +117% due to higher carbon returns to the soil *(Emissions and Soils CS)*.
- With adaptation of new varieties and irrigation, crop yields will most likely increase. More modest increases are likely for potato compared to maize and groundnut, however soybean yields could still decrease. High Confidence *(Climate Impacts CS)*.
- The mean percentage change to crop production with RCP8.5, scenario ht is 564% (range across climate models 522 to 584%; 0/18 climate models are outliers) *(Food Production CS1)*.
- Effectively implemented irrigation and crop varietal improvements across the country result in significantly reduced yield shock rates. Medium Confidence *(Climate Shocks CS)*.

Scenario quadrant: High climate risk (RCP8.5) / low market efficacy (LT)

- With maize being the dominant crop, adopting cropping systems that ensure that maize and legumes are grown together or in rotation on the same fields will help replenish soil nutrients that are removed during harvest.
- Maintaining adequate organic soil cover will help reduce erosion, which can cause significant decline in soil organic carbon stock, soil fertility and crop yield.

These implication statements are based on:

- A scenario characterised an increase in crop diversity with non-maize crop areas increasing by 20%, although maize remains the crop with the highest growing area *(Scenario Description)*.
- National greenhouse gas (GHG) emissions under the LT scenario are -26% compared to the year 2000. At the same time soil organic carbon stocks changed by -11% *(Emissions and Soils CS)*.
- The mean percentage change to crop production with RCP8.5, scenario lt is -1% (range across climate models -11 to 6%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to irrigation water with RCP8.5, scenario lt is 1959% (range across climate models 1360 to 2500%; 1/18 climate models are outliers). This becomes mean 1994%, range 1397 to 2500% after removing the lower limit outliers *(Irrigation CS).*

Scenario quadrant: Low climate risk (RCP2.6) / high market efficacy (HT)

- Increasing livestock production may lead to increased use of crop residues as livestock feed thereby reducing biomass availability for use as mulch, leading to a decline in soil carbon stock
- Integrated crop-livestock production systems that ensure appropriate use of both crop residues and livestock manure as soil amendments will help to maintain and/or enhance soil health in such a way that neither livestock nor crop production is negatively affected

These implication statements are based on:

- National greenhouse gas (GHG) emissions under the HT scenario are +245% compared to the year 2000 based on the increase in crop and livestock production. At the same time soil organic carbon stocks changed by +134% due to higher carbon returns to the soil *(Emissions and Soils CS)*.
- The mean percentage change to crop production with RCP2.6, scenario ht is 252% (range across climate models 233 to 271%; 0/18 climate models are outliers) *(Food Production CS1)*.
- The mean percentage change to livestock meat production with RCP2.6, scenario ht is 250% (range across climate models 230 to 266%; 0/18 climate models are outliers) *(Food Production CS2)*.

- The mean percentage change to livestock dairy production with RCP2.6, scenario ht is 183% (range across climate models 169 to 193%; 0/18 climate models are outliers) *(Food Production CS2)*.

Scenario quadrant: Low climate risk (RCP2.6) / low market efficacy (LT)

- Under predominantly rainfed agricultural system, availability of adequate soil water for crops will be a challenge.
- Changes to land management practices such as adoption of conservation agriculture (where this is suitable) and targeted fertilizer application will help to improve soil health including build-up of soil organic carbon, which will lead to greater crop yields.

These implication statements are based on:

- National greenhouse gas (GHG) emissions under the LT scenario are -18% compared to the year 2000. At the same time soil organic carbon stocks changed by -6% *(Emissions and Soils CS)*.
- The mean percentage change to crop production with RCP2.6, scenario lt is 8% (range across climate models -4 to 16%; 0/18 climate models are outliers) *(Food Production CS)*.
- The mean percentage change to irrigation water with RCP2.6, scenario lt is 40% (range across climate models 25 to 72%; 1/18 climate models are outliers). This becomes mean 38%, range 25 to 71% after removing the upper limit outliers *(Irrigation CS)*.