The Asia-Pacific region is highly disaster prone and susceptible to climate variability and extremes due to widely varying geography from coastal territories to mountainous areas, and tropical to polar climates. Long-term food security in this region necessitates estimation of future food production, including the assessment and adoption of adaptation/mitigation strategies. The present paper serves to highlight climate variability of the recent past and for future projected scenarios, and its impact on food production. It serves to recommend adaptive climate-smart agricultural measures, from local practices to policy level initiatives to help address 2030 Agenda for Sustainable Development and future food security of the Asia-Pacific region.

Keywords: food security, climate change, climate variability, Asia-Pacific, climate-smart agriculture

JEL classification: Q01
I. INTRODUCTION

The Asia-Pacific region is highly susceptible to changes in climate variability, with extensive coastlines, many small island countries, and a widely varying geography from low-lying coastal territories to elevated mountainous areas, and tropical to polar climates. According to the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) intensifying greenhouse gas (GHG) emissions have affected all continents and most oceans, with many natural systems disrupted by climate change, particularly increases in temperature. Evidence is seen in rising carbon dioxide concentrations, global mean temperatures and sea levels, and changing precipitation patterns. Relative to 1850–1900, global mean surface temperature by 2100 is likely to increase by 1.4°C to 4.4°C under five different GHG emissions scenarios (Shared Socioeconomic Pathways (SSP), SSP1-1.9 to SSP5-8.5). The frequency and intensity of heavy precipitation events have increased since the 1950s. The average annual global land precipitation is projected to increase by 0–13 per cent under emissions scenarios (SSP1-1.9 to SSP5-8.5) by 2081–2100, relative to 1995–2014. Intensity and frequency of hot extremes including heatwaves, plus agricultural and ecological droughts, are likely to increase in some regions in the future (IPCC, 2021). Sea levels rose by 0.20 m between 1901 and 2018. Given Asia-Pacific topography, this poses an existential threat to many countries in the region.

There is growing consensus that under future climate change scenarios and in the absence of adaptive measures severe impacts on crop production can be expected. Negative impacts for coastal regions are expected to be exacerbated, with overall losses of production and increased food security risks. Causes include the additive effects of erosion, increased contamination of groundwater and estuaries by saltwater incursion, tropical cyclones and storm surges, heat stress and drought. For crops where the Asia-Pacific region accounts for a significant proportion of world production, the impacts will not only be local, but also global. Similar impacts are possible for livestock production. Pacific Island Countries and other nations dependent upon fisheries face potential yield and species loss due to climate change induced alteration of turbidity, salinity and temperature (Barnett, 2020).

The present paper provides a consolidated view detailing important climate change impacts and how they can affect food security. Food security has four main dimensions: physical availability; economic and physical access to food; food utilization; and stability of the other three dimensions over time (FAO, 2015). The focus of the present paper is on the first dimension, physical availability, which largely depends on production. It provides an outline of how mitigation and adaptation measures are inextricably linked to the achievement of the Sustainable Development Goals (SDGs) embodied in the 2030 Agenda for Sustainable Development. Acknowledging
the importance of this and other top-down policy frameworks for action, the present paper serves to propose that complementary local and broad scale implementation of climate-smart agricultural practices throughout the Asia-Pacific region are essential for achieving and ensuring sustainable agriculture and food security.

Section II covers past changes and trends of climate; section III examines future climate projections; section IV documents likely impacts of climate change on food security; section V covers agriculture and sustainable development policy in the Asia-Pacific region; and section VI provides conclusions and makes recommendations.

II. CLIMATE: PAST CHANGES AND TRENDS

Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the past 2,000 years. Hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe (IPCC, 2021). The frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas for which observational data are sufficient for trend analysis, and human-induced climate change is likely the main driver.

2.1 Temperature

Relative to 1850–1900, the rise in global average surface temperature accelerated from +0.89°C for 2001–2010, to +1.09°C for 2011–2020. Larger increases were seen over land than sea, for instance, +1.59°C versus +0.88°C during 2011–2020. As reported by IPCC (2012), since 1950, cold days and nights in the Asia-Pacific region have decreased in number, warm days and nights have increased in number, and heat wave frequency has increased.

2.2 Precipitation

The frequency of occurrence of more intense rainfall in many parts of Asia has increased while the number of rainy days and total annual amount of precipitation has declined. Precipitation trends, including extremes, are characterized by strong variability, with both increasing and decreasing trends observed in different parts of the Asia-Pacific region and in different seasons (Hijioka and others, 2014). In northern Asia, observations indicate some increasing trends of heavy precipitation events, but in Central Asia, no coherent trends were found. In West Asia, a weak but non-significant downward trend in mean precipitation was observed in recent decades, and an increase in intense weather events. In South Asia, seasonal rainfall shows a declining trend in inter-decadal variability, with more frequent relative rainfall deficits
in monsoons. The frequency of heavy precipitation is increasing, while light rain events are decreasing. In South-East Asia, annual total wet-day rainfall along with extreme rainfall has increased. In Peninsular Malaysia during the southwest monsoon season, total rainfall and the frequency of wet days decreased, but rainfall intensity increased over much of the region. During the northeast monsoon total rainfall and the frequency of extreme rainfall intensity increased over the peninsula.

During 1961–2000, locations to the northeast of the South Pacific Convergence Zone became wetter, while locations to the southwest became drier.

III. CLIMATE: FUTURE PROJECTIONS

3.1 Temperature

Under the Representative Concentration Pathway (RCP) scenarios for GHG emissions through the year 2100, changes in projected mean annual temperature exceed 2°C above the 1961–1990 baseline over most land areas by 2050 under the high-emissions scenario, RCP8.5, and range from greater than 3°C in South and South-East Asia, to greater than 6°C in high latitudes by 2100. Projected changes are less than 2°C above the same baseline by both 2050 and 2100 under the lower emissions scenario, RCP2.6, with the exception of 2°C to 3°C rises in the highest latitudes (Hijioka and others, 2014). The projections show not only rising average temperatures, but also rising numbers of hot days.

According to the IPCC Sixth Assessment Report Summary for Policymakers, (IPCC, 2021) global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Projections show that every additional 0.5°C of global warming will cause increases in the intensity and frequency of extremes, including heatwaves (very likely), heavy precipitation (high confidence) and drought intensity and frequency in some regions (medium confidence).

It is widely accepted now that many changes in the climate system correspond to increasing global surface temperature.

3.2 Precipitation

A 7 per cent global increase in extreme daily precipitation events is projected for each 1°C of warming (high confidence). The proportion of intense tropical cyclones (category 4–5) is projected to increase globally (IPCC, 2021). Average annual global land precipitation is projected to increase by 0–5 per cent under SSP1-1.9, and by
1–13 per cent under SSP5-8.5 by 2081–2100 relative to 1995–2014. Increases are projected in high latitudes, the equatorial Pacific and parts of the monsoon regions, but decreases are projected in parts of the subtropics and tropics for SSP2-4.5, SSP3-7.0 and SSP5-8.5 (very likely). Monsoon precipitation is projected to increase globally in the medium to long term, particularly in South Asia, South-East Asia and East Asia (high confidence).

3.3 Sea level rise

Global mean sea level rise of 0.20 m during 1901–2018 has occurred due to ice loss on land and thermal expansion caused by ocean warming. Thermal expansion accounted for 50 per cent of sea level rise during 1971–2018 while accelerating losses from glaciers contributed 22 per cent, ice sheets 20 per cent and changes in land-water storage 8 per cent (IPCC, 2021). The average rate of rise was 1.3 mm yr⁻¹ during 1901–1971, increasing to 1.9 mm yr⁻¹ during 1971–2006, and further increasing to 3.7 mm yr⁻¹ during 2006–2018 (high confidence). Approximately two thirds of global coastline have a projected relative rise within ±20 per cent of the global mean increase. The Asia-Pacific region is highly vulnerable to rising sea levels, which increase the risk of floods. Some Pacific Island Countries have experienced a rate of sea level rise that is four times the global average (Nurse and others, 2014).

In the Asia-Pacific region, sea level is expected to rise 3–16 cm by 2030 and 7–50 cm by 2070 (Preston and others, 2006). With a sea level rise of 40 cm by 2100, the population facing floods in coastal areas will increase from 13 million to 94 million, with 60 per cent of that population found in South Asia (Bangladesh, India, Pakistan, Myanmar and Sri Lanka) and 20 per cent found in South-East Asia (Indonesia, the Philippines, Thailand and Viet Nam).

IV. CLIMATE IMPACTS ON FOOD SECURITY

Climate change will affect all four dimensions of food security: availability; accessibility; utilization; and stability (figure 1). An IPCC Special Report found that climate-related risks to food security are projected to increase with global warming of 1.5°C and increase further with global warming of 2°C (IPCC, 2018). Shifts in land suitability will likely lead to an increase in suitable cropland at higher latitudes and a decline of cropland at lower latitudes. Fluctuating crop yields and local food supply will make achieving food security more difficult. Semi-arid and subhumid regions will be affected most, reducing yields of crops, livestock and productivity. Potential price increases and negative income effects associated with climate change also have implications for food accessibility (ADB, 2013).
4.1 Crop production

Since the IPCC Fifth Assessment Report, studies have demonstrated strong relationships between observed climate variables and crop yields that indicate...
expected future warming will have severe impacts on crop production (Mavromatis, 2015). Climate and crop simulations indicate that climate changes during 1981-2010 have decreased global mean yields of maize, wheat, and soybeans by 4.1, 1.8 and 4.5 per cent, respectively, relative to preindustrial climate, even when carbon dioxide fertilization and agronomic adjustments are considered (Iizumi and others, 2018). Dryland settlements are vulnerable to climate change driven food security risks, with drylands constituting over 40 per cent of the earth’s land area, and home to 2.5 billion people. Agricultural production in the Pacific Island Countries is likely to be adversely affected by climate change in a number of ways. The effects of climate change are highly heterogeneous with some regions gaining, nevertheless the overall effect is negative.

**Cereals in South Asia.** In South Asia, for example, climate change will likely bring a substantial reduction in aggregate crop production. Cereal’s production could be decreased up to approximately 31, 24, 25 and 6 per cent (figure 2) by 2050 as compared to 2011, in Bangladesh, Pakistan, Sri Lanka and India respectively (Alvi and others, 2021).

**Figure 2. Change in cereal production by 2050 compared to 2011 under climate change scenario**

Source: Alvi and others (2021).

**Rice.** On average, rice yields are projected to decline. By 2050 in South Asia climate change could reduce irrigated crop yields of rice (14–20 per cent), wheat (32–44 per cent); maize (2–4 per cent) and soybeans (9–18 per cent) relative to 2010 (Rosegrant, Tokgoz and Bhandary, 2013). Yoon and Choi (2020) reported that irrigation requirements for rice in the Republic of Korea under RCP4.5 would decrease by 2100 because of an increase in projected rainfall, but under RCP8.5 rainfall decreases
therefore increasing the need for irrigation. Rice yields in the Republic of Korea were projected to decrease monotonically from the 2020s to the 2040s due to the increase in days that could cause high temperature damage (Kim and others, 2021). Warming and increasing extreme climate events are expected to reduce crop yields, including rice production in China, threatening food security. Chinese rice growth duration is anticipated to decease by >30 days by the end of the twenty-first century, and average rice yield will decline approximately 5, 7 and 15 per cent respectively in the periods 2011–2040, 2041–2070 and 2071–2100 (Ding and others, 2020).

**Wheat in Australia.** Variations in average growing season temperature of ±2°C in wheat growing regions of Australia could reduce production by 50 per cent (Asseng and others, 2015). Zheng and others (2012) showed Australian wheat life cycles could be shortened by up to 42 days by 2050. Simulations by Hochman, Gobbett and Horan (2017) for 50 sites showed that, other factors held constant, declines in rainfall and rising maximum temperatures account for a potential water-limited yield decline of 27 per cent during 1990–2015, with elevated carbon dioxide concentrations avoiding a further 4 per cent loss. Actual yields however experienced a modest growth over the period, mainly due to an unprecedented rate of technological gains – underlining the value of investing in technological adaptation and mitigation strategies.

**Maize.** Negative impacts on maize yields are projected (-4 to -14 per cent) compared to 1981–2010 in China (Xiao and others, 2020) and (-11 to -27 per cent) compared to 1982–2012 for West Bengal, India (Shrivastava, Panda and Chakraborty, 2021).

**Groundnut and soybean (rainy season) and wheat and chickpea (post-rainy season) in India.** Results from an Asia-Pacific Network project in India (Huda and others, 2012) showed that increasing temperature trends are likely to reduce rainy-season crop yields by approximately 10–15 per cent and post-rainy season crop yields by approximately 20–25 per cent. As a result, breeding heat tolerant wheat and chickpea varieties needed to be strengthened.

**Wheat-maize in China.** Increasing temperatures in China have favoured wheat-maize systems in the north, while rice-based systems in the south are disadvantaged. Maize varieties with a longer growing season for northern China are less frost tolerant and breeding is required to overcome this deficiency. The Government of China established a disaster fund to deal with extreme weather events as part of an adaptation strategy. Research should concentrate on practices to reduce GHG emissions and water use by rice and to ensure biological nitrogen fixation (Huda and others, 2012).

Generally, across maize, sunflowers, wheat and rice, most projected climate change related yield losses around the world could be explained by a shortened growth duration.
For coastal communities, severe droughts, intense floods, saltwater incursion of ground water and estuaries, plus tropical cyclones and associated storm surges reduce both crop yields and total production, increasing the risk to food security. Tropical cyclones are a significant cause of lost agricultural production (Barnett, 2020). As agriculture is the main source of food, livelihood and income for many Pacific island communities, extreme weather events can have a highly critical impact.

In a sea level rise scenario of 1 m, up to 7.7 million ha of croplands would be submerged, while in a 3 m scenario, up to 16.1 million ha would be lost. Rice is expected to be the most affected, losing 4.9 million ha under the 1 m scenario and 10.5 million ha under the 3 m scenario, followed by wheat (0.6 million ha and 1.2 million ha) and maize (0.5 million ha and 0.9 million ha). Given the cultivation of 150 million ha of rice, the forecasted losses would significantly affect global rice production and, hence, prices (ADB, 2013).

South Asia, East Asia and the Pacific are consistently found to suffer in terms of reduced crop yields by 2080 under RCP8.5. Impacts may be more severe for South Asia than for East Asia and the Pacific.

4.2 Fruits and vegetables

The effect of climate change on vegetable crops was estimated to be similar to the effect on grain crops. The initial effect of increased carbon dioxide on vegetables is mostly beneficial for production, but it may alter quality parameters. Heat stress due to higher temperatures reduces fruit numbers produced by fruiting vegetables, and it speeds up the development of annual vegetables, thereby shortening their time for photo assimilation. Luck and others (2012) reported that relative to 1972–2010, by 2050 the productivity of potato crops in India may be reduced by 23–30 per cent (Nadia district) and 28–32 per cent (Hooghly district) and in Bangladesh by 7–26 per cent (Bogra district) and 18–31 per cent (Munshiganj district). In Australia, relative to the same period, there is a chance of small yield reductions (3 per cent) in tropical Queensland, and <1 per cent in temperate Victoria. Potato production will likely become more reliable over southern Australia. Tuber formation in sweet potato is significantly reduced at temperatures above 34°C. Projected temperature increases of 2.0°C–4.5°C by 2100 could significantly reduce sweet potato production in lowland areas of Papua New Guinea but may increase cacao production in Vanuatu and Fiji while increased flooding may affect sugar cane production in Papua New Guinea and Solomon Islands (Bell and others, 2016).

4.3 Crop protection

Direct impacts of climate change on pests include alteration of reproduction, development, survival and dispersal, whereas indirect impacts include the relationships
between pests, their environment and other insect species such as natural enemies, competitors, vectors and mutualists (Prakash and others, 2014). Warren and others (2018) estimated that about 49 per cent of insects, some of which are considered agricultural pests or disease vectors while others are considered mutualists, will change the spatial ranges within which they thrive by about 50 per cent by 2100 given a 3.2°C increase in the global average temperature. If warming can be limited to 2°C the estimate of affected insect species reduces to 18 per cent.

According to Deutsch and others (2018), warming will accelerate the growth of wheat-pest populations in temperate climates. For rice grown in tropical zones a decrease in the growth of rice-pest populations is predicted, while for maize grown in both temperate and tropical regions mixed responses in pest population growth could be expected. Overall, the estimated likely net effect is for crop yield reductions. By 2100 under 2°C of global warming, the pest-related global yield losses from wheat, rice and maize are likely to increase by 46 per cent, 19 per cent and 31 per cent, respectively, when compared to current levels of loss. Furthermore, each additional degree of temperature rise could cause global yield losses to increase by a further 10–25 per cent, due to insect pests (Dunne, 2018).

Hence adaptation and mitigation strategies are crucial. Huda and others (2007) noted that integrated pest management approaches should be complemented with pest epidemiology and consideration of local socioeconomic capacity. They caution that responses such as the use of herbicides, pesticides or other biological approaches need careful optimization to minimize negative externalities such as pollutant damage or unintended ecological damage.

Integrated pest management related research in the Asia-Pacific region undertaken by Huda and others (2009) demonstrated the feasibility of identifying specific quantitative pest/disease-climate relations for location-specific selected pests and diseases. Relationships displaying high correlations between climate and incidence of disease were developed for late leaf spot in peanuts for India and Cambodia; alternaria blight in mustard for India and Bangladesh; and sclerotinia in canola for Australia and India. These relationships enabled identification of critical climate-related decision thresholds to inform adaptation or mitigation strategies.

Earlier onset of potato late blight is likely in future decades in India, Bangladesh and Australia. Disease severity is likely to reduce by 5–7 per cent in 2031–2040 compared to 1981–2010 in West Bengal, India. However, in growing areas of Bangladesh, disease severity could shift in either direction. Increases of up to 12 per cent are expected in northern Bangladesh and reductions of around 7 per cent in central Bangladesh. Potato late blight is expected to be less problematic in the tropical north than elsewhere in Australia (Luck and others, 2012).
4.4 Overall impacts on food security

The physical availability dimension of food security depends on domestic production and imports. Declining per capita food production is a function of several factors: population growth; private and public investment in agriculture; availability of labour, water and land; input costs; and disasters.

Across Pacific Island Countries, in the decade up to 2006 per capita food production declined and dependence on imported foods increased, including cereals which are virtually all imported. Indeed, this has affected trade deficits, and total food availability in the Pacific islands is increasingly becoming a function of the ability to pay for food imports (Barnett, 2020). The Hindu-Kush Himalayan region is experiencing an increase in extremes, with farmers facing more frequent floods and prolonged droughts that have decreased yields and increased food insecurity (Hussain and others, 2016).

A summary of the impacts of climate change on yield of major food sources in selected Asia-Pacific countries is provided in table 1.

Table 1. Impact of climate change
(a) On change in crop yield by mid to late twenty-first century

<table>
<thead>
<tr>
<th>Crop</th>
<th>Region/Country</th>
<th>Change in yield (percentage)</th>
<th>Base year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>South Asia</td>
<td>-14% to -20%</td>
<td>2010</td>
<td>Rosegrant, Tokgoz and Bhandary (2013)</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>-5% to -15%</td>
<td>2002–2012</td>
<td>Ding and others (2020)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>-2 to -15%</td>
<td>2005</td>
<td>Teng, Caballero-Anthony and Lassa (2016)</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>-7 to -18%</td>
<td>1960–2004</td>
<td>Iqbal and others (2009)</td>
</tr>
<tr>
<td></td>
<td>Viet Nam</td>
<td>-6 to -24%</td>
<td>2013</td>
<td>Teng, Caballero-Anthony and Lassa (2016)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Wetland rice:</td>
<td>-3 to -6%</td>
<td>1976–2011</td>
<td>Khairulbahri (2021)</td>
</tr>
<tr>
<td></td>
<td>Dry land rice:</td>
<td>-2 to -4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Global average</td>
<td>-10 to -25% per +1°C temp</td>
<td>2003-2008</td>
<td>ADB (2021)</td>
</tr>
<tr>
<td></td>
<td>impact</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 1. (continued)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Region/Country</th>
<th>Change in yield (percentage)</th>
<th>Base year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>South Asia</td>
<td>-32% to -44%</td>
<td>2010</td>
<td>Rosegrant, Tokgoz and Bhandary (2013)</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>-36 to -41%</td>
<td>2006–2012</td>
<td>Wang and others (2021)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>Irrigated: -1 to -8%</td>
<td>1986–2005</td>
<td>Daloz and others (2021)</td>
</tr>
<tr>
<td></td>
<td>Bangladesh</td>
<td>-7 to -35%</td>
<td>2000–2019</td>
<td>Islam and others (2022)</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>+18 to +48%</td>
<td>2006–2015</td>
<td>Alvar Beltran (2021)</td>
</tr>
<tr>
<td></td>
<td>South West Australia</td>
<td>-26% to -49%</td>
<td>1980–2010</td>
<td>Taylor and others (2018)</td>
</tr>
<tr>
<td>Maize</td>
<td>South Asia</td>
<td>-2% to -4%</td>
<td>2010</td>
<td>Rosegrant, Tokgoz and Bhandary (2013)</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>-4 to -14%</td>
<td>2001–2009</td>
<td>Xiao and others (2020)</td>
</tr>
<tr>
<td></td>
<td>India (West Bengal)</td>
<td>-11 to -27%</td>
<td>1982–2012</td>
<td>Shrivastava, Panda and Chakraborty (2021)</td>
</tr>
<tr>
<td>Soyabean</td>
<td>South Asia</td>
<td>-9% to +18%</td>
<td>2010</td>
<td>Rosegrant, Tokgoz and Bhandary (2013)</td>
</tr>
</tbody>
</table>

(b) On global sea level rise and crop area loss (million ha)

<table>
<thead>
<tr>
<th>Sea level rise</th>
<th>Rice</th>
<th>Wheat</th>
<th>Maize</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1 metre</td>
<td>4.9</td>
<td>0.6</td>
<td>0.5</td>
<td>ADB (2013)</td>
</tr>
<tr>
<td>+3 metre</td>
<td>10.9</td>
<td>1.2</td>
<td>0.9</td>
<td>ADB (2013)</td>
</tr>
</tbody>
</table>

Analysis of yield projection estimates against the most recently available statistical data (2019) of the Food and Agriculture Organization of the United Nations (FAO) (FAOSTAT, 2022) can provide an indication of the relative effort and investment that might be considered in addressing findings such as those in table 1.

**Rice.** China, India and Viet Nam represent 28, 24 and 6 per cent, respectively, of global rice production (FAOSTAT, 2022). Projected losses of 10, 9 and 15 per cent, respectively (figure 3) may lead to 3, 2 and 1 per cent reductions in global rice...
production, warranting the development of policies and plans to address the situation. As rice is a staple food, reduced production would increase the hunger index.

**Figure 3. Expected change of overall rice yield under future climate scenario by 2100**

Source: See references in table 1.

**Wheat.** Asia contributes around 44 per cent of global wheat production, of which China (17.5 per cent) and India (13.5 per cent) occupy the major share. A projected reduction in wheat yield for China of 39 per cent will be a great threat to global food supply (figure 4). In India non-irrigated wheat will suffer a reduction in productivity of approximately 20 per cent, which could be minimized with judicious irrigation management.

**Figure 4. Expected change of overall wheat yield under future climate scenario by 2100**

Source: See references in table 1.
Maize. As China contributes 23 per cent of global maize production, a 9 per cent decline in its productivity (figure 5) corresponds to a 2 per cent reduction in global production, which will be a concern for food security. Similarly, the contribution of India to global production may be reduced to 1.9 per cent from 2.4 per cent (FAOSTAT, 2022).

Figure 5. Expected change of overall maize yield under future climate scenario by 2100

Source: See references in table 1.

In summary, comparing the limited data available in figures 3, 4 and 5 to FAO statistical data provides a basis for identifying where targeted investments could be beneficial. For example, in India to offset climate related wheat losses an effective strategy could centre on investments in irrigation and crop water use efficiency.

Comprehensive coverage of the entire Asia-Pacific region and the discernment of the relative merits of investment across the full spectrum of geographies, agricultural production and potential adaptation and mitigation strategies is beyond the scope of the present paper and is a worthy topic for further investigation.

V. AGRICULTURE AND SUSTAINABLE DEVELOPMENT POLICY IN THE ASIA-PACIFIC REGION

The present section highlights selected Sustainable Development Goals and policy measures of the United Nations Framework Convention on Climate Change for the agriculture sector in addressing food security issues relevant to climate change and endorses the bottom-up approach of climate-smart agriculture as a practical means toward implementation.
Agriculture features prominently in the 2030 Agenda. It is relevant to each of the 17 Sustainable Development Goals. Rapidly rising population rates, limited arable land and diminishing natural resources across the Asia-Pacific region will impose significant economic reliance on the agriculture sector for long-term sustainability.

Sustainable Development Goal 2 considers the adequacy of food production. Agricultural productivity has risen in many Asian countries, but opportunity remains to lift productivity further. However, there is also a dominance of small-holder farmers in the agriculture sector of many countries within the Asia-Pacific region, who are often unable to afford the costs, lack adequate access to capital, have varying levels of education and access to the support of national extension services, research and development infrastructure to engender and sustain the adoption of better technological farming systems. This is a major risk to the achievement of Goal 2, which includes ending hunger and ensuring access by all people to safe, nutritious and sufficient food all year round by 2030.

According to FAO (2021), hunger as measured by the prevalence of undernourishment globally increased from 630 million to 690 million between 2014 and 2019. By extrapolation, this trend could reach more than 840 million people by 2030, including 330 million people in Asia.

Agriculture still accounts for a significant proportion of gross domestic product (GDP) in many countries across the Asia-Pacific region, especially those recognized as developing countries. For those countries, structural transformation is central to achieving overall sustainable national economic growth and full productive employment for all, which are aims of Sustainable Development Goal 8. Truelove and others (forthcoming) cite value chain analysis and modelling as providing a sound basis upon which to develop and enact plans for guiding structural adjustments.

Responsible climate action will provide substantial opportunities for modernizing infrastructure, creating new jobs, and promoting greater prosperity. Coordinated efforts will be required to achieve the targets enumerated under the 17 Sustainable Development Goals. The aim of the 26th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2021 was to accelerate action toward meeting the goals of the Paris Agreement. Doing so would assist in addressing Goal 13 regarding urgent action to combat climate change and its impacts. The Conference of the Parties emphasized the need for more lending to help poor countries shift out of fossil fuel based energy generation (aligning with Goal 7), to build societies better adapted to the impacts of climate change and to recover from damage caused by extreme weather events. Notably, besides biomass and bioenergy, other forms of renewable energy substitution for fossil fuels (e.g. wind, solar, geothermal, hydroelectric) are increasingly being adopted by producers and
applied to practices such as conservation tillage and precision farming (e.g. fertilizer and chemical application and precision irrigation) to further reduce GHG emissions (Ahmed and others, 2017).

Climate-smart agriculture provides a set of practical responses that can scale from locally based actions through to broad-scale policy application, contributing towards and complimenting high level actions such as the Sustainable Development Goals and initiatives of UNFCCC. The Koronivia Joint Working Group for Agriculture at the Conference of the Parties highlighted that actions should be inclusive of strategies and modalities to scale up implementation of best practices, innovations and technologies to increase resilience and sustainable production in agricultural systems (UNFCCC, 2021).

Climate-smart agriculture is defined as an integrated approach to managing cropland, livestock, forests and fisheries that aims to support food security under projected climate change through sustainable and equitable transitions of agricultural systems and livelihoods (Aggarwal and others, 2018). It is designed to increase productivity and income through enhancing the ability of communities to adapt to climate change and weather extremes, and decreasing GHG emissions (Steenwerth and others, 2014).

Huda and others (2012) highlighted how an understanding of the impact of climate change on key crops could enable Asia-Pacific farmers (in India, China and Australia), community workers and policy agencies to work together in better preparing for and adapting to climate change, through changes to existing policies and practices. It was identified that adaptation measures such as supplementary irrigation, breeding new heat- and drought-tolerant seed varieties and concentrating agriculture in geographically suited locations would be effective. Sustainable adaptation strategies explored for paddy ecosystems included relocation of croplands, shifting planting dates and developing new varieties, along with smart management of water and fertilizer (Ding and others, 2020; Yoon and Choi, 2020).

Transplantation date shifts and raising drainage outlets were evaluated as pragmatic and robust strategies to mitigate climate change impacts on paddy rice cultivation (Kim and others, 2021). Heat tolerant varieties were identified as a preferred adaptation strategy for subtropical regions. Recently, sweet potato has been cultivated as part of food security and climate change adaptation projects in Pacific communities due to its climatic and ecological resilience (McGregor and others, 2016).

While greater fertilizer use may help maintain or increase food production, it may also result in greater overall GHG emissions, not to mention increases in pollutants or potential soil degradation effects. Nevertheless, increased nutrient use efficiency through adoption of better management practices can assist in maintaining and
increasing yield, contributing to both food security and climate change mitigation (Sapkota and others, 2017). Mixed farming systems integrating crops, livestock, fisheries and agroforestry could also help maintain crop yields in the face of climate change, assisting in the adaptation to changes in climate variability and minimizing GHG emissions by improving the nutrient flows (Newaj, Chaturvedi and Handa, 2016).

Options to increase resilience to climate risks include livelihood diversification within and across fisheries, aquaculture and agriculture. In Bangladesh, fishing pressure on post-larval prawns has increased as displaced farmers have shifted to fishing following saltwater intrusions of agricultural land (Ahmed Occhipinti-Ambrogi and Muir, 2013). Adaptation strategies proposed by FAO (2014) include the introduction of fishponds in areas susceptible to flood and drought; cage fish aquaculture in human-made reservoirs; transition to different species, polyculture and integrated systems for diversification and resilience systems; combined rice-fish farming; and transitions to alternative livelihoods. In terms of mitigation, Ahmed and others (2017) found that conversion of 25 per cent of total aquaculture area to integrated aquaculture-agriculture ponds has the potential to sequester 95.4 million tonnes of carbon per year.

Soil carbon sequestration together with biological nitrogen fixation has been shown to improve land health and underlying ecosystem services. Further enhancement is possible through improved agricultural land management practices such as incorporation of trees (agroforestry, fruit crops, etc.) within farms or in hedges (manure addition, green manures, cover crops, etc.). This promotes greater soil organic matter and nutrient content (and thus soil organic carbon) and improves soil structure. Such measures have the potential to reduce GHG emissions from the agroforestry sector by up to 0.1–5.7 gigatons per year (Griscom and others, 2017).

All of the above results are within the remit of climate-smart agriculture and are of great importance not only for food security, but also for the sustainable use of water resources (Ding and others, 2020). Changes in temperature and precipitation, and increased evapotranspiration may require significant increases in irrigation for many countries and regions. However, having sufficient water resources is a prerequisite, with water itself a central management issue for climate change. Increasing or adjusting irrigation requirements is another potentially effective adaptation measure.

Huda and others (2019) conducted a multi-faceted climate-smart livelihood improvement programme at two small-holder agriculture-based villages in West Bengal, India, to implement many of the above-mentioned strategies. Dependence on seasonal monsoon rainfall was removed through enhancement of local water resources, enabling diversification of crops from wet season rice only to a variety of year-round crops. Mushroom and worm cultivation were introduced, along with fish farming, planting of fruit trees on water resource bunds and a range of new soil
nutrient management practices. Built upon a base of sustainable practices adopted by the villagers, the result was a movement from largely subsistence farming to fledgling small commercial enterprises attracting diversified year-round income, improved diets for villagers and the active participation of women in the workforce.

Rosegrant, Tokgoz and Bhandary (2013) posit that the entire climate change-related increase in childhood malnutrition in Pacific Island Countries could be eliminated through a policy package, including: (a) an increase in research and extension spending (up to 2 per cent of agricultural GDP); (b) optimization of crop varieties to climate change; (c) increasing the use of nitrogenous fertilizers from 30 to 50 kg/ha; and (d) applying public incentives to increase fish and livestock production.

Since so many people in the Asia-Pacific region are not receiving adequate nutrition through their diets, regional production, availability and affordability of nutritious foods will almost certainly need to increase to eradicate malnutrition in line with Goal 2.

VI. CONCLUSIONS AND RECOMMENDATIONS

Widespread recent research for selected major crops across the Asia-Pacific region strongly supports a growing consensus around forecasts of an overall decline in yields by the mid to late twenty-first century unless extensive adaptive and mitigative actions are taken and sustained. Given that the region accounts for a substantial portion of global production, forecasted declines constitute a threat to global food security. Further assessment of yield expectations for all agricultural outputs across the region is required to discern the relative merits of investments.

The forecasted impacts on agriculture are set against a backdrop of rapidly increasing populations and recently observed increases in poverty. For many countries and communities across the region, these factors coincide with a high economic and livelihood dependence on the agriculture sector. Moreover, many of the economies in question are still developing with agriculture sectors characterized by a high proportion of small-holders that are currently ill-placed to compete sustainably beyond their local communities. Thus, in many cases across the region, it will be central to reform and restructure agriculture and the infrastructure and relationships upon which agriculture depends, to address the climate change and sustainable development challenges which are inextricably linked.

Top-down approaches embodied within the IPCC process and 2030 Agenda are essential to meeting these challenges, yet they are insufficient alone. In terms of adaptive measures to boost agricultural productivity and livelihoods, the following suite of climate-smart agricultural measures and strategies can be enacted either bottom up or at scale:
• Suitable crop(s) selection under changing climate variability, based upon local climate, geography and available/planned infrastructure;

• Livelihood diversification within and across fisheries, aquaculture and agriculture;

• Adaptation of crops to environmental stresses, including cropping systems and varieties designed to match water availability with crop water requirements and avoid exposure to extreme temperature and limited water supply conditions during critical crop development phases;

• Breeding or genetic engineering of new varieties with better adapted phenology, such as heat and salt tolerance, shorter maturity duration and pest-disease resistance;

• More efficient and sustainable water and nutrient management practices, noting that integrated watershed management will play a major role in sustaining productivity;

• Quantification of specific pest-disease-climate-location relationships, and use of identified critical climate-decision thresholds against climate projection data to inform adaptation and mitigation strategies;

• Projected changes in yield across countries/regions and all major crops should be used along with historic FAO statistical data to inform the relative investment and effort in adaptation and mitigation strategies that should be made, spatially and by crop across the Asia-Pacific region;

• Enhancement of renewable energy substitution for fossil fuels (e.g. wind, solar, geothermal, and hydropower) in agricultural production systems;

• Increased integration of agroforestry (fruits crop) in agriculture production systems.

In practice the scoping, design and implementation of such measures necessitate collaboration between multidisciplinary experts, governments and producers. It may also call for international collaboration, as best practices in several areas may have been developed and implemented outside the Asia-Pacific region. In any case the food-security risks highlighted in the present paper for the Asia-Pacific region are not unique. For example, Kray and others (2022) showed that global warming of 3°C on average by 2050 could cause up to 30 per cent of maize growing areas in Africa to be lost due to climate change.

The opportunistic uptake of suggested measures in a bottom-up fashion by individual producers and their local communities will have a cumulative positive
effect and change the livelihoods of those directly involved. However, optimizing the benefits on a broader scale across the Asia-Pacific region (with consequential global positive externalities) will require coordinated planning, implementation and investments from States, nations, and regional areas, each customized to suit their particular circumstances. Where they are involved, special attention should be given to enabling small-holder farming communities with infrastructure, capacity-building and financial means to sustainably adopt new practices, and this should include assistance in opening and servicing new markets.

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