Adaptation of the agricultural sector to the effects of climate change in arid regions: competitive advantage date palm cropping patterns under water scarcity conditions
Ahmed M. Alabdulkader, Ahmed I. Al-Amoud and Fawzi S. Awad

ABSTRACT
This research paper highlights the adverse effects of climate change on the agricultural sector in Saudi Arabia and the actions taken to adapt to these adverse effects. Special focus was given to the potential to optimise the reallocation of scarce water resources among the competitive advantage date palm cropping regions in Saudi Arabia using a mathematical sector modelling approach. The results showed great potential for Saudi Arabia to adapt to the adverse effects of climate change by optimising the date palm cropping pattern in accordance with its scarce water resources and limited cultivated lands. The optimised scenario would result in a high net annual return, equivalent to about 881.76 million US$ year$$^{-1}$$, and an increase on the water use return from about 0.97 US$ cm$$^{-1}$$ in the base year to approximately 1.31 US$ cm$$^{-1}$$ The optimised scenario would also provide the opportunity to reduce the allocated date palm cropping area by approximately 4% (from approximately 118,250 hectares to approximately 113,446 hectares) and to reduce the water demand by approximately 1% (from 681.06 million cubic metres (MCM) per year to approximately 674.28 MCM per year).

Key words | mathematical sector modelling national adaptation programme, net annual return, water use return

INTRODUCTION
Climate change is currently the overriding environmental issue. Its effect varies greatly among countries and socioeconomic sectors. The agricultural sector is one of the sectors which is most highly vulnerable to the adverse effects of climate change, and this vulnerability becomes more evident in arid and semi-arid regions. The significant role of the agricultural sector is recognised worldwide as a key driver for achieving sustainable economic, social and environmental development. Accordingly, the international community, particularly in developing countries, has given special consideration to mitigating the adverse effects of climate change on the agricultural sector and to adapting to these effects in a sustainable manner. The actions aimed at adaptation in the agricultural sector include the adjustment of date planting, crop varieties, crop relocation (IPCC 2007) and the more efficient use of water, for example through improved agricultural practices, irrigation management and resilient agriculture (IPCC 2014).

Developing a national adaptation programme for the agricultural sector in Saudi Arabia in response to the adverse effects of climate change has become essential as it is the sector responsible for ensuring national food security and is the greatest consumer of water resources in the country, accounting for an average of approximately 86% of the total water supply throughout the last three decades. Approximately 72% of the water consumed by the agricultural sector is pumped from non-renewable water resources.

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This research paper highlights the adverse effects of climate change on the agricultural sector in Saudi Arabia and the actions taken to adapt to these adverse effects. Special focus has been given to the potential to optimise the reallocation of scarce water resources among the competitive advantage date palm cropping regions in Saudi Arabia using a mathematical sector modelling approach. The date and date palm sector is one of the leading competitive economic sectors in Saudi Arabia, and has received great recognition at global level. Saudi Arabia holds the first rank worldwide in terms of its cultivated date palm area, which encompasses approximately 156 thousand hectares, and the third rank in date production, with more than 1000,000 tons being produced in the year 2011 (FAO 2013).

Achieving the objectives of this research paper would add value to the serious endeavour of Saudi Arabia to adapt to and to combat the adverse effects of climate change, thus joining the international communities to achieve the ultimate objective of the United Nations framework convention on climate change, i.e., to raise the levels of public awareness and understanding about the magnitude of the adverse effects of climate change on agriculture in arid and semi-arid regions, including Saudi Arabia. In addition, this research paper is an attempt to translate the pertinent national adaptation policies and targets into real actions, including optimising the reallocation of scarce water resources among the competitive advantage crops in Saudi Arabia within the strategic framework of rational water use, thus providing decision-makers with evidence-based results to translate policies into real actions.

A review of the literature revealed the actions which have been taken to address the adaptation of agriculture to the adverse effects of climate change, including optimising the cropping patterns according to limited water resources. Olarinde et al. (2014) applied instrumental variables analysis to assess the impact of using different climate change adaptation policies on crop yields and the associated effect on market values in Nigeria. Awareness of adaptation policies was found to have a significant positive impact on crop yields and their market values. Using a statistical crop yield model, Ortiz-Bo Bea (2013) assessed the impact of temperature and drought stresses on corn crops in the USA. Ortiz-Bo Bea showed that the potential impact of climate change on agriculture was driven by both temperature and drought stress and that the relative role of both stresses was found to correlate with the scenario of climate change and the ability of farmers to adapt. Marshall et al. (2015) applied a regional environment and agriculture program to explore the implications of a shifting regional water balance for agricultural production under different climate change scenarios in the USA. The analysis considered adjustments in irrigated production and constraints to and opportunities for adaptation arising from changing patterns of precipitation, and in the projected shift in the demand for water use in various sectors. Results of the analysis showed that limited water resources are likely to constrain the ability of some regions to respond to climate change conditions. Cunha et al. (2012) applied matching methods to analyse the adverse effects of climate change on the Brazilian agriculture sector, considering irrigation adoption as a potential adaptation strategy. The results showed that irrigation can be an effective tool to counteract the harmful effects of climate change. Hatfield (2012) discussed agriculture adaptation practices to increasing variability in climate change in the USA. Malcolm et al. (2012a, 2012b) evaluated the effect of using various adaptation strategies on crop production and prices in the USA under different climate change scenarios. The US agricultural sector was found to be more responsive to changes in resources and market forces, and to have the potential to minimise the aggregate disturbance to supply of and demand for commodities resulting from a production reallocations adaptation strategy. Quiggin et al. (2010) applied a simulation model to analyse the impact of climate change adaptation and mitigation on irrigated agriculture in Australia. The results of the analysis showed that in the absence of effective mitigation strategies, climate change will have considerable adverse effects on irrigated agriculture, but these adverse effects will be offset through changes in land and water use. Nelson et al. (2009) investigated the impact of climate change on agriculture and its consequences on global food security, and estimated the required investment to offset such consequences on human well-being. The adverse effects of climate change were noticed on crop yields and prices, and on human well-being, especially in developing countries. Additional funding for adaptation programmes of at least $7 billion annually is needed to offset the adverse effects of climate change on agriculture and human well-being.
Al-abdulkader *et al.* (2012) formulated a mathematical sector model to optimise the cropping pattern of different crop groups, including cereals, fruits, forages and vegetables, which would maximise the annual net return of the agricultural sector in Saudi Arabia and efficiently reallocate water resources among competing crops. The optimised cropping pattern in Saudi Arabia showed a potential return of about 2.42 billion US$ per year, an approximate 53% saving in water use and an approximate 48% reduction in cultivated land use compared to the base-year cropping pattern.

Khan (2011) applied a stochastic dynamic programming model to identify the optimal allocation of water resources that maximises the expected net social return from rice production in Bangladesh, and the associated optimal adaptation policies to the impacts of climate change in the Bangladesh agricultural sector. Kaur *et al.* (2010) formulated a linear programming model to determine the optimal cropping patterns in Punjab agriculture which maximise net returns and use water resources efficiently. The suggested optimised cropping patterns ensured a saving of groundwater equivalent to about 25% without any change in the net return from crop production. Haouari & Azaiez (2001) proposed a mathematical model to determine the optimal cropping patterns under water scarcity conditions in arid regions which maximises the net return of farmers.

**STUDY AREA**

Saudi Arabia is located in the far southwest of Asia, between 213.75°–236.25° longitude and 16.5°N–32.5°N latitude. It covers an area of approximately 2.25 million km² and has a population of approximately 28 million. The average annual rainfall in Saudi Arabia is less than 150 mm in most regions. Most of Saudi Arabia is characterised by extreme heat and aridity, with high temperatures and low precipitation, which in turn cause a high rate of evapotranspiration, a decrease in soil moisture and soil erosion. Such harsh climatic conditions adversely affect agricultural produce and water resources in Saudi Arabia (PME 2011).

The ecosystem of Saudi Arabia is highly sensitive to any level of climate change and most regions are highly vulnerable to climate variability, particularly that related to desertification and deterioration of water resources. In most regions of Saudi Arabia, climate change would raise the levels of reference evapotranspiration by approximately 1–4.5% with an increase of approximately 1 °C, and by approximately 6–19.5% with an increase of approximately 5 °C. The demands for irrigation water would increase by approximately 602 million cubic metres (MCM) with an increase of approximately 1 °C, and by approximately 3,122 MCM with an increase of approximately 5 °C. The expected yield of field crops and fruit trees would experience losses that range from 5% to more than 25%. In many regions of Saudi Arabia, the water demand exceeds the sustainable water supply level. Conventional strategies for increasing the water supply in Saudi Arabia are neither reliable enough to meet growing needs nor able to cope with the uncertainty arising from increased climate change and climate variability. Sustained national efforts are therefore required to manage water demand among competitive economic sectors (PME 2011).

Figures 1 and 2 illustrate the observed temperature changes and the projected warming under a low-emission mitigation scenario and a high-emission scenario. The projected global temperature increase over the next few decades was similar to that across different emission scenarios. Saudi Arabia was projected with very strong agreement as being among nations that will observe a temperature change during the forthcoming decades under different emission scenarios (IPCC 2014).

**ACTIONS TAKEN TO ADAPT TO CLIMATE CHANGE**

Saudi Arabia has put forward a number of policies and targets to adapt the agricultural sector to the adverse effects of climate change, as follows (Ministry of Economy and Planning 2010):

- Determining the agricultural crops to be grown and the associated water demand within the strategic framework of rational water use.
- Expanding the use of reclaimed wastewater for agricultural purposes.
- Continuing efforts to achieve ecological balance through combating desertification and via the conservation and development of pastures and forests.
Enhancing the competitiveness of agricultural activities, especially those of small- and medium-sized farms and relaxing the terms of investment in agriculture.

Encouraging innovation and supporting agricultural R&D.

Intensifying methods for the rationalisation of water use for all purposes.

Achieving a balance between water development and water consumption.

Expanding the application of advanced methods and technologies for both production and consumption.

Expediting the issuance of the National Water Plan.

Developing appropriate mechanisms for determining the shares of various uses of water.

Promoting integrated management of water resources and water demand.

Upgrading the scientific, technical and developmental capacities of the human resources operating in the sector.
- Intensifying efforts to provide water and sanitation services reliably at a high level of efficiency.
- Working towards issuing new water tariffs to incentivise the rational use of water for all purposes and its conservation.
- Encouraging the private sector to invest in this sector by providing incentives and simplifying procedures.
- Encouraging the trend towards reliance on renewable energy sources by the sector, particularly solar energy.

**METHODS AND MATERIALS**

The potential for reallocating scarce water resources among competitive advantage crops in Saudi Arabia has been considered among actions taken to adapt to the adverse effects of climate change on the national agriculture sector. Special attention was given to the date palm and date sector. Seven major date palm production regions (study regions) in Saudi Arabia were considered to optimise the reallocation of scarce water resources in accordance with the regional competitive advantage. The considered study regions include Riyadh, Makkah, Madinah, AlQasim, Eastern, Alwadi and Najran (Figure 3).

A mathematical sector model was applied to realise the ultimate objective of this paper, which comprises four key components: an objective function, resource constraints, national commodity balance and national trade balance.

The objective function of the model was to optimise the 1-year date palm cropping pattern, which maximises the net annual return subject to the limited water supply and the cultivated land in the study regions, given marketing and trade balance constraints.

\[
Z' = \sum_{j=1}^{J} f(W_j) - \sum_{r=1}^{R} C_{jr} X_{jr} - I_j' + E_j' \quad \text{for all } j, r
\]

where:

- \(Z'\) = Net annual return, in terms of US $ year\(^{-1}\).
- \(f(W_j)\) = Welfare function, measuring the area under the excess demand equation for the \(j\)th crop in year \(y\).
- \(C_{jr}\) = Average cost for the \(j\)th crop in the \(r\)th study region, in terms of US$ ton\(^{-1}\).
- \(X_{jr}\) = Average yield for the \(j\)th crop in the \(r\)th study region, in terms of tons hectare\(^{-1}\).
- \(I_j'\) = Net national imports for the \(j\)th crop in year \(y\), in terms of tons.
- \(E_j'\) = Net national exports for the \(j\)th crop in year \(y\), in terms of tons.

\(J\) = Date palm.
\(R = 1, 2, 3, \ldots 7\) study regions.

Two crucial resource constraints were considered in the model: the water supply and the cultivated land. The water supply constraint was visualised in two forms: a monthly water supply and an annual water supply. The monthly water supply was applied to ensure that the irrigation water requirements of date palm in the study regions did not exceed the available level of the monthly water supply. On the other hand, the annual water supply constraint was applied to ensure that the annual irrigation water requirements for date palm in the study regions did not exceed a certain level of water annually. The mathematical illustration of the resource constraints can be presented as follows:

\[
\sum_{i} a_{ir} X_{jr} \leq b_{ir} \quad \text{for all } i, r
\]

\[
\sum_{j} a_{wjr} X_{jr} \leq w_{jr} \quad \text{for all } r
\]

where:

- \(a_{ir}\) = Input–output coefficients indicating the amount of the \(i\)th resources required to produce one hectare of the \(j\)th crop in the \(r\)th study region at time \(t\).
- \(X_{jr}\) = Annual yield for the \(j\)th crop in the \(r\)th study region in terms of tons per hectare.
- \(b_{ir}\) = Maximum amount of the \(i\)th resource available in the \(r\)th study region at time \(t\).
- \(a_{wjr}\) = Irrigation water requirements (w) for the \(j\)th crop in the \(r\)th study region in year \(y\).
- \(w_{jr}\) = Maximum water supply in year \(y\) in the \(r\)th study region.

\(T = 1, 2, 3 \ldots 12\) months.

The national commodity balance of date palm comprised three main elements: the average supply in the
study regions ($G_{yr}^S$), the net national import ($NI_{yr}^N$) or net national export ($NE_{yr}^N$) and the excess national demand ($Ed_{yr}^N$). The national commodity balance for the net imports of date palm aimed at ensuring that the sum of the study regions’ supplies and the net national imports was greater than or equal to the excess national demand.

On the other hand, the national commodity balance for the net exports of date palm aimed at ensuring that the sum of the regional supplies was greater than or equal to the excess demand plus net national exports of date palm. The national commodity balance was illustrated mathematically for the net imports and net exports of
date palm as follows:

\[ Ed_{jn}^y - NI_{jn}^y - GS_{jr}^y \leq 0 \]  
\[ Ed_{jn}^y + NE_{jn}^y - GS_{jr}^y \leq 0 \]

where:

- \( Ed_{jn}^y \) = Excess national demand for the \( j \)th crop in year \( y \).
- \( NI_{jn}^y \) = Net national imports for the \( j \)th crop in year \( y \).
- \( GS_{jr}^y \) = Average production for the \( j \)th crop in year \( y \).
- \( Ed_{dn}^y \) = Excess national demand for exporting date palm in year \( y \).
- \( NE_{dn}^y \) = Net national exports of date palm (d) in year \( y \).
- \( GS_{dr}^y \) = Average production of exported date palm (d) in year \( y \).

The national trade balance was presented to ensure that the net national imports (\( NI_{jn}^y \)) of date palm did not exceed a maximum limit for net national imports (\( I_{jn}^y \)) annually, and the net national exports (\( NE_{jn}^y \)) for date palm did not exceed a maximum limit for net national exports (\( E_{jn}^y \)) annually, as illustrated mathematically as follows:

\[ NI_{jn}^y \leq I_{jn}^y \]  
\[ NE_{jn}^y \leq E_{jn}^y \]

The mathematical sector model input–output coefficients for the mathematical sector model including the average values of the following parameters: average yield, average market price, average production cost and average water requirements for date palm in the study regions in Saudi Arabia (Al-Amoud et al. 2010).

Approximately 40 farms were subjected to field surveys and some statistical year books were investigated to calculate the required input–output coefficients.

RESULTS AND DISCUSSION

Optimising the cropping pattern of date palm in Saudi Arabia in accordance with the competitive advantage of the study regions revealed a great potential for Saudi Arabia to adapt to the adverse effects of climate change by restructuring its date palm cropping pattern according to its scarce water resources and limited cultivated land.

The optimised date palm cropping pattern (the optimised scenario) recommended an increase in the allocated areas for date palm in regions with high efficient use of scarce water resources, more productive land and high returns of water use. The recommended increase in

<table>
<thead>
<tr>
<th>Regions</th>
<th>Average yield (ton ha(^{-1}))</th>
<th>Average market price (US$ ton(^{-1}))</th>
<th>Average production costs (US$ ha(^{-1}))</th>
<th>Net return (US$ ha(^{-1}))</th>
<th>Average annual water requirements (cm yr(^{-1})ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riyadh</td>
<td>5.96</td>
<td>1,245.33</td>
<td>3,622.13</td>
<td>3,800.05</td>
<td>5,466</td>
</tr>
<tr>
<td>Makkah</td>
<td>6.85</td>
<td>1,066.67</td>
<td>2,528.80</td>
<td>4,777.87</td>
<td>6,202</td>
</tr>
<tr>
<td>Madinah</td>
<td>5.33</td>
<td>2,590.22</td>
<td>4,336.27</td>
<td>9,469.61</td>
<td>7,231</td>
</tr>
<tr>
<td>AlQasim</td>
<td>4.53</td>
<td>1,955.56</td>
<td>5,721.10</td>
<td>3,137.59</td>
<td>5,369</td>
</tr>
<tr>
<td>Eastern</td>
<td>11.30</td>
<td>1,562.96</td>
<td>3,099.20</td>
<td>1,456.28</td>
<td>5,371</td>
</tr>
<tr>
<td>Alwadi</td>
<td>5.20</td>
<td>8,56.67</td>
<td>2,457.87</td>
<td>1,996.80</td>
<td>5,682</td>
</tr>
<tr>
<td>Najran</td>
<td>5.23</td>
<td>1,644.45</td>
<td>3,582.67</td>
<td>5,017.78</td>
<td>4,832</td>
</tr>
</tbody>
</table>

allocated areas associated with the optimised scenario is about 235, 127, 83, 54 and 28% in Najran, Eastern, Madinah, Makkah and Alwadi regions, respectively. On the other hand, the optimised scenario recommended lowering the allocated areas to regions with inefficient use of scarce water resources, less productive land and low return for water use such as Riyadh and AlQasim regions. The recommended decrease in allocated area of the optimised scenario is about 82 and 42% in Riyadh and AlQasim regions, respectively. Figure 4 compares the allocated area for date palm cropping pattern under the base year and the optimised scenarios.

The optimised scenario entailed a potential reduction of the allocated date palm cropping area in study regions by approximately 4%, from approximately 118,250 hectares to approximately 113,446 hectares (Table 2).

![Figure 4](https://iwaponline.com/jwcc/article-pdf/7/3/514/373372/jwc0070514.pdf)

**Table 2** | Date palm cropping pattern – the base year versus the optimised scenario in Saudi Arabia

<table>
<thead>
<tr>
<th>Regions</th>
<th>Base year (ha)</th>
<th>Relative importance of the base year date palm cropping area at a national level (%)</th>
<th>Optimised date cropping area (ha)</th>
<th>Relative importance of the optimised date palm cropping area at a national level (%)</th>
<th>Difference for the base year vs. the optimised cropping area (ha)</th>
<th>Difference for the base year vs. the optimised cropping area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riyadh</td>
<td>36,300</td>
<td>30.7</td>
<td>6,709</td>
<td>5.9</td>
<td>(29,591)</td>
<td>(82)</td>
</tr>
<tr>
<td>Makkah</td>
<td>9,800</td>
<td>8.3</td>
<td>17,899</td>
<td>15.8</td>
<td>8,099</td>
<td>83</td>
</tr>
<tr>
<td>Madinah</td>
<td>18,800</td>
<td>15.9</td>
<td>28,958</td>
<td>25.5</td>
<td>10,158</td>
<td>54</td>
</tr>
<tr>
<td>AlQasim</td>
<td>34,800</td>
<td>29.4</td>
<td>18,059</td>
<td>15.9</td>
<td>(16,741)</td>
<td>(48)</td>
</tr>
<tr>
<td>Eastern</td>
<td>11,300</td>
<td>9.6</td>
<td>25,702</td>
<td>22.7</td>
<td>14,402</td>
<td>127</td>
</tr>
<tr>
<td>Alwadi</td>
<td>3,950</td>
<td>3.3</td>
<td>5,064</td>
<td>4.5</td>
<td>1,114</td>
<td>28</td>
</tr>
<tr>
<td>Najran</td>
<td>3,300</td>
<td>2.8</td>
<td>11,055</td>
<td>9.7</td>
<td>7,755</td>
<td>235</td>
</tr>
<tr>
<td>Total</td>
<td>118,250</td>
<td>100</td>
<td>113,446</td>
<td>100</td>
<td>(4,804)</td>
<td>(4.1)</td>
</tr>
</tbody>
</table>

Source: Study analysis.

Numbers between brackets have a negative sign.
Similarly, the optimised scenario recommended the reallocation of scarce water resources to regions with highly efficient use and high return for water resources such as Najran, Eastern, Madinah, Makkah and Alwadi regions by about 235%, 127%, 83%, 54% and 28%, respectively, from regions with inefficient use and low returns of irrigated water such as Riyadh and AlQasim regions, by about 82% and 42%, respectively (Figure 5).

Adopting the optimised scenario would entail a potential reduction of water demand by approximately 1%, from 681.06 MCM per year (million cm yr\(^{-1}\)) to approximately 674.28 million cm yr\(^{-1}\) that could be reallocated to the other competing economical crops in Saudi Arabia (Table 3).

The net annual return associated with the optimised scenario will be equivalent to approximately 881.75 million

![Figure 5](image_url)  
**Figure 5** | Allocation of water resources under the base year and the optimised scenarios in Saudi Arabia.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Water requirements (\text{cm yr}^{-1} \text{ ha}^{-1})</th>
<th>Base year water requirements (\text{million cm yr}^{-1})</th>
<th>Optimised water requirements (\text{million cm yr}^{-1})</th>
<th>Water saving (base year vs. optimised) (\text{million cm yr}^{-1})</th>
<th>(per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riyadh</td>
<td>5,466</td>
<td>198.42</td>
<td>36.67</td>
<td>(161.74)</td>
<td>(82)</td>
</tr>
<tr>
<td>Makkah</td>
<td>6,202</td>
<td>111.01</td>
<td>111.01</td>
<td>50.23</td>
<td>83</td>
</tr>
<tr>
<td>Madinah</td>
<td>7,231</td>
<td>135.94</td>
<td>209.40</td>
<td>73.45</td>
<td>54</td>
</tr>
<tr>
<td>AlQasim</td>
<td>5,369</td>
<td>186.84</td>
<td>96.96</td>
<td>(89.88)</td>
<td>(48)</td>
</tr>
<tr>
<td>Eastern</td>
<td>5,371</td>
<td>60.78</td>
<td>60.69</td>
<td>77.35</td>
<td>127</td>
</tr>
<tr>
<td>Alwadi</td>
<td>5,682</td>
<td>22.44</td>
<td>28.77</td>
<td>6.33</td>
<td>28</td>
</tr>
<tr>
<td>Najran</td>
<td>4,832</td>
<td>15.95</td>
<td>53.42</td>
<td>37.47</td>
<td>235</td>
</tr>
<tr>
<td>Total</td>
<td>681.06</td>
<td>674.28</td>
<td>(6.79)</td>
<td>(1.00)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Study analysis.  
Numbers between brackets have a negative sign.  

![Table 3](image_url)  
**Table 3** | Optimised water requirements – the optimised date palm cropping pattern versus the base year date palm cropping pattern in Saudi Arabia.
US$ year\(^{-1}\), compared to approximately 660.98 million US$ year\(^{-1}\) for the base year (Figure 6).

In addition, the return for water use will increase on average from 0.97 US$ cm\(^{-1}\) in the base year to approximately 1.31 US$ cm\(^{-1}\) under the optimised scenario. Table 4 summarises the net annual return associated with the base year compared to the optimised scenario, the potential difference between the two scenarios, and the potential return on water use.

**CONCLUSIONS**

Saudi Arabia is considered to be among the nations that are most vulnerable to the adverse effects of climate change.

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**Figure 6** | Net annual return under the base year and the optimised date palm cropping pattern scenarios in Saudi Arabia.

**Table 4** | Net annual return—the base year versus the optimised date palm cropping pattern in Saudi Arabia

<table>
<thead>
<tr>
<th>Regions</th>
<th>Net return (US$ ha(^{-1}))</th>
<th>Base year (million US$ yr(^{-1}))</th>
<th>Optimised model (million US$ yr(^{-1}))</th>
<th>Difference base vs. optimised cropping area (million US$ yr(^{-1}))</th>
<th>Return on water use (US$ cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riyadh</td>
<td>3,800.05</td>
<td>137.94</td>
<td>25.49</td>
<td>(112.45)</td>
<td>0.70</td>
</tr>
<tr>
<td>Makkah</td>
<td>4,777.87</td>
<td>46.82</td>
<td>85.52</td>
<td>38.70</td>
<td>0.77</td>
</tr>
<tr>
<td>Madinah</td>
<td>9,469.61</td>
<td>178.03</td>
<td>56.66</td>
<td>(96.19)</td>
<td>1.31</td>
</tr>
<tr>
<td>AlQasim</td>
<td>3,137.59</td>
<td>109.19</td>
<td>56.66</td>
<td>(52.53)</td>
<td>0.58</td>
</tr>
<tr>
<td>Eastern</td>
<td>14,562.28</td>
<td>164.55</td>
<td>374.28</td>
<td>209.73</td>
<td>2.71</td>
</tr>
<tr>
<td>Alwadi</td>
<td>1,996.80</td>
<td>7.89</td>
<td>10.11</td>
<td>2.22</td>
<td>0.35</td>
</tr>
<tr>
<td>Najran</td>
<td>5,017.78</td>
<td>16.56</td>
<td>55.47</td>
<td>38.91</td>
<td>1.04</td>
</tr>
<tr>
<td>Total</td>
<td>660.98</td>
<td>881.75</td>
<td></td>
<td>220.78</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Source: Study analysis.
Numbers between brackets have a negative sign.
Optimising the cropping pattern in Saudi Arabia according to the regional competitive advantage was considered as one of the actions taken to adapt to the adverse effects of climate change. This paper applied a mathematical sector model to optimise the date palm cropping pattern that efficiently uses the limited water resources and cultivated lands and maximises the net annual return. The results showed great potential for Saudi Arabia to adapt to the adverse effects of climate change. The optimised scenario considered the efficient use of scarce water resources and limited cultivated land and generated a high net annual return. The results efficiently uses the limited water resources and cultivated lands and maximises the net annual return. The results showed great potential for Saudi Arabia to adapt to the adverse effects of climate change. The optimised scenario considered the efficient use of scarce water resources and limited cultivated land and generated a high net annual return, equivalent to approximately 881.76 million US$ year⁻¹, compared with approximately 660.98 million US$ year⁻¹ for the base year. Consequently, the return for water use would increase on average from 0.97 US$ cm⁻¹ in the base year to approximately 1.31 US$ cm⁻¹ under the optimised scenario. The optimised scenario would also provide Saudi Arabia with the potential to reduce its date palm cropping area by approximately 4%, from approximately 118,250 hectares to approximately 113,446 hectares, and to reduce its water demand by approximately 1% from 681.06 MCM per year to approximately 674.28 MCM per year. These promising findings could change the national trends towards the optimisation of the crop patterns in Saudi Arabia, and thus enhance the potential of the agricultural sector to adapt to the adverse effects of climate change.

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