How Can the Country of Jordan Optimise its Agriculture Industry?

Introduction

Jordan is a small developing country in the Middle East, a region known for its desert landscapes, where only 10% of the country's land is considered arable land. The dry conditions lead to water scarcity being a large problem facing the country, resulting in a per capita water supply to be "200m^3 per year which is almost one-third of the global average" (Abboud, 2016). These conditions create extremely difficult settings for the agriculture industry to thrive, and therefore much of the food demand is supplied from imports, leading to high spendings by the country.

Given that Jordan is resource poor and import dependent, optimising land and water allocations to achieve optimised production of crops is extremely important. This is also crucial due to Jordan having one of the fastest growing populations in the world as a result of regional turmoil and refugee influx, leading to increasing pressures on resources and growing demand for food.

Two indicators are used to test the success of the agriculture industry: gross production value (GPV) and self-sustainability ratio (SSR). Therefore, the study is broken down to two parts; the first optimises the agriculture industry based on GPV, the second on SSR. Previous studies focus on optimising farming strategies and irrigation, yet a vacuum exists in optimising the dollar-value and self-sustainability based on land-water allocations.

Data

Data is obtained from the Food and Agriculture Organisation (FAO) and Jordan's Ministry of Water and Irrigation (MWI) . Data is from the year 2013.

Table 1 summarises the data obtained. Table 2 is summarises the data calculated from the data obtained.

Table 1

Variable	Unit	Source
Arable land	Hectares (Ha)	FAO
Jordan's total water used in irrigation	m^3	MWI
Crop type	N/A	FAO
Area harvested per crop	Hectares (Ha)	FAO
Total production per crop	Ton	FAO
Total Gross Production Value (GPV) per crop	Dollars ($)	FAO
Total imports per crop	Ton	FAO
Total exports per crop	Ton	FAO
Global Average Water Footprint per crop	m^3/ton	

Table 2

Variable Calculated	Unit	Source
Production per unit area per crop	Tons/Ha	N/A
Production per unit water per crop	Tons/m^3	N/A
Area per unit production per crop	Ha/ton	N/A
Water per unit production per crop	m^3/ton	N/A
Gross Production Value (GPV) per ton per crop	$/ton	N/A
Demand per crop	Ton	N/A
Self Sustainability Ratio (SSR) per crop	%	N/A
Jordan's Average Water Footprint per crop	m^3/ton	N/A

On a country scale, data on arable land and total water used in irrigation were obtained. Arable land includes land currently cultivated and land not yet cultivated but has the potential to. Total arable land is used rather than remaining arable land not currently cultivated because the paper is aiming at rethinking the entire agricultural allocation in the country given the extremely limited resources of land and water. Total water used in irrigation in 2013 reflects the water available for the agriculture sector in this study.

Data on 50 different crops grown in Jordan was obtained. 10 crops were removed from the dataset because the data indicated that there was more export of each of these 10 crops than there was production. This creates skewed results and therefore they are not considered in this study. The land cultivated in 2013 for each of the 10 crops and the water used in their irrigation were both subtracted from the total arable land and total water available for irrigation.

The global average water footprint represents the amount of water each crop requires to produce 1 ton of crop production. By calculating the amount of water needed for the crop production in Jordan in 2013 based on the global average water footprint, we get about three-fold of the water actually used in irrigation in Jordan. This is taken into account by finding Jordan's average water footprint per crop by multiplying the global average for each crop by the factor calculated, equal to 0.3392.

Production per unit area (and per unit water) is found by dividing each crop's production in 2013 by its area harvested (and its water used for its irrigation calculated by multiplying Jordan's average water footprint x production). Area per unit production (and water per unit production) is calculated by dividing the area harvested (and the water used) for each crop in 2013 and dividing it by the production of that crop. The demand for each crop is calculated by adding production to imports and subtracting exports. The self-sustainability ratio (SSR) is calculated by dividing the production over the demand.

Analysis

The analysis is broken down to two parts: part one explains the methodology, results and discussion of optimisation based on GPV, part two for SSR.

Part one: How can the country of Jordan optimise the GPV ($) of its agriculture industry?

Methodology

We set up a linear programming model that will optimise the GPV given the two main constraints: water and arable land.

The objective function is:

$$Z = \sum_{i=1}^{n} c_i X_i$$

Where *i* represents the variable number (there are 40 variables), c is the coefficient corresponding to the variable (the GPV per ton per crop), and X represents the decision variable (each of the 40 variables is a type of crop). See below:

$$Z = \sum_{i=1}^{n} c_i X_i = \textit{1989 almonds + 672 apples + ... (40 variables)}$$

The two main constraints facing the country's agriculture industry are arable land and water availability. For each of the 40 decision variables (crops), the coefficient represents the area and water per 1 ton production. The total area allocations and water allocations must be less than or equal to the total area and water available. See below:

Water constraint: *2730 almonds + 279 apples +...(40 variables) ≤ 481,000,000*
Land constraint: *0.14 almonds + 0.06 apples + ...(40 variables) ≤ 190,304*

In order to run this model, upper bounds for each crop must be defined. Otherwise, the results will indicate that we must only plant the most efficient crop in terms of water and land allocations for maximum GPV outcome.

Therefore, the linear programming model is run under multiple scenarios according to upper bound land and water allocations seen in tables 3 and 4

Table 3

Maximum land allocation	Ha
2.5%	4757.6
5%	9515.2
10%	19030.4
15%	28545.6
20%	38060.8
25%	47576
50%	95152
100%	190304

Table 4

Maximum water allocation	m^3
2.5%	10957847.7
5%	21915695.4
10%	43831390.81
15%	65747086.21
20%	87662781.62
25%	109578477
50%	219156954
100%	438313908.1

Taking the first scenario in table 3, the maximum land allocations is 2.5%, meaning that the maximum land that each crop is able to occupy is 4757.6 hectares. 2.5% is the smallest percentage used because it represents (1/40)%. Scenarios under maximum land allocations are run first and compared, then scenarios under maximum water allocations are run and compared.

Results

Tables 5 and 6 display the optimal land allocation (water allocation) for each crop under different allocation scenarios. The bottom of the tables shows the total land (water) used in each limitation scenario, the remaining land (water), and the total GPV ($) based on each the scenario.

The results also include three graphs for land allocation scenarios and three for water allocation scenarios. Figures 1 and 4 display the allocation of land (water) per crop, figures 2 and 5 show the GPV per crop based on the land (water) allocation, figures 3 and 6 show the total production in tons per crop based on the land (water) allocation. The x-axis for figures 1-6 was adjusted for visualisation purposes.

Figure 7 displays the relationship between restriction scenarios and GPV outcome.

Table 5: Arable land allocations (Ha) under land restriction scenarios

Crop	2.5%	5%	10%	15%	20%	25%	50%	100%
Almonds, with shell	0	0	0	0	0	0	0	0
Apples	4757.6	0	0	0	0	0	0	0
Apricots	4757.6	0	0	0	0	0	0	0
Bananas	4757.599999	0	0	0	0	0	0	0
Barley	0	0	0	0	0	0	0	0
Beans, green	4757.599998	4937.04915	0	0	0	0	0	0
Cabbages and other brassicas	0	0	0	0	0	0	0	0
Carrots and turnips	4757.600001	9515.200001	19030.4	28545.6	38060.80001	15632.10812	0	0
Cauliflowers and broccoli	4757.599999	0	0	0	0	0	0	0
Cherries	4757.6	9515.2	19030.4	15723.81892	0	0	0	0
Chick peas	0	0	0	0	0	0	0	0
Chillies and peppers, green	4757.599999	9515.199999	0	0	0	0	0	0
Cucumbers and gherkins	4757.599999	9515.2	0	0	0	0	0	0
Dates	0	0	0	0	0	0	0	0
Eggplants (aubergines)	4757.600001	0	0	0	0	0	0	0
Figs	0	0	0	0	0	0	0	0
Garlic	4757.6	9515.199997	19030.4	28545.6	38060.8	47576	0	0
Grapefruit (inc. pomelos)	0	0	0	0	0	0	0	0
Grapes	4757.6	9515.2	19030.4	0	0	0	0	0
Lemons and limes	4757.6	0	0	0	0	0	0	0
Lentils	0	0	0	0	0	0	0	0
Lettuce and chicory	3111.778546	0	0	0	0	0	0	0
Maize	0	0	0	0	0	0	0	0
Melons, other (inc.cantaloupes)	4757.599999	9515.199999	2218.728348	0	0	0	0	0
Okra	4757.6	9515.2	19030.4	28545.6	38060.8	47576	53487.54438	0
Olives	0	0	0	0	0	0	0	0
Onions, dry	4757.6	0	0	0	0	0	0	0
Oranges	4757.6	0	0	0	0	0	0	0
Pears	4757.6	0	0	0	0	0	0	0
Peas, green	4757.6	9515.2	0	0	0	0	0	0
Plums and sloes	0	0	0	0	0	0	0	0
Potatoes	4757.599999	9515.199999	19030.4	28545.6	10036.42673	0	0	0
Pumpkins, squash & gourds	4757.599999	9515.199998	0	0	0	0	0	0
Sorghum	0	0	0	0	0	0	0	0
Strawberries	4757.6	9515.2	19030.4	28545.6	38060.80001	47576	95152	122452.9443
Tobacco, unmanufactured	0	0	0	0	0	0	0	0
Tomatoes	4757.6	9515.199999	19030.4	0	0	0	0	0
Vetches	0	0	0	0	0	0	0	0
Watermelons	4757.6	0	0	0	0	0	0	0
Wheat	0	0	0	0	0	0	0	0
Land used (Ha)	117294.1785	128634.6491	154461.9283	158451.8189	162279.6268	158360.1081	148639.5444	122452.9443
Remaining land	73009.82146	61669.35086	35842.07166	31852.18107	28024.37325	31943.89188	41664.45562	67851.05574
GPV ($)	1714887695	2313010261	3170318944	3840008170	4393731027	4715872064	5332321823	5556511192

Figure 1: Land Area Planted (Ha) Per Crop Under Land Allocation Restriction Scenarios

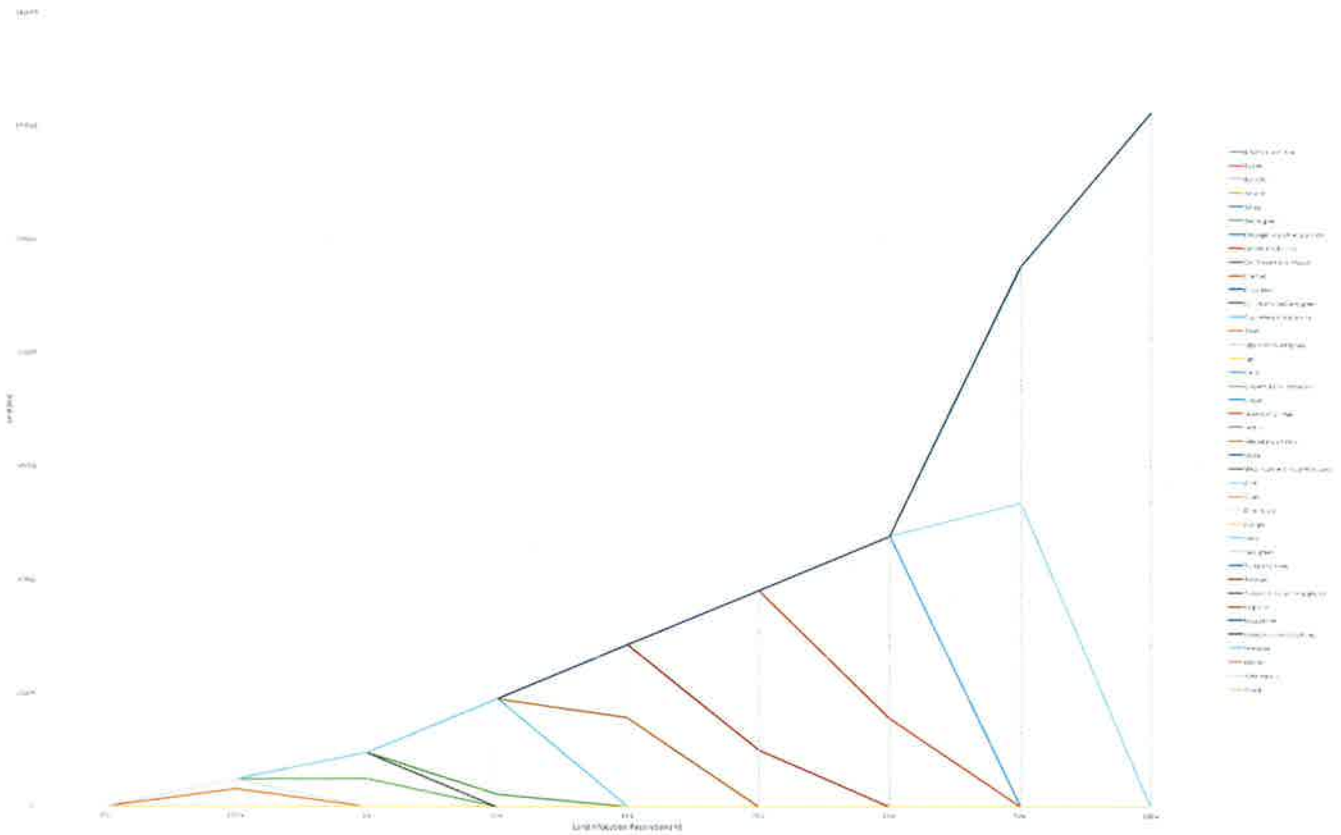


Figure 2: Production (Ton) Per Crop Under Land Allocation Restriction Scenarios

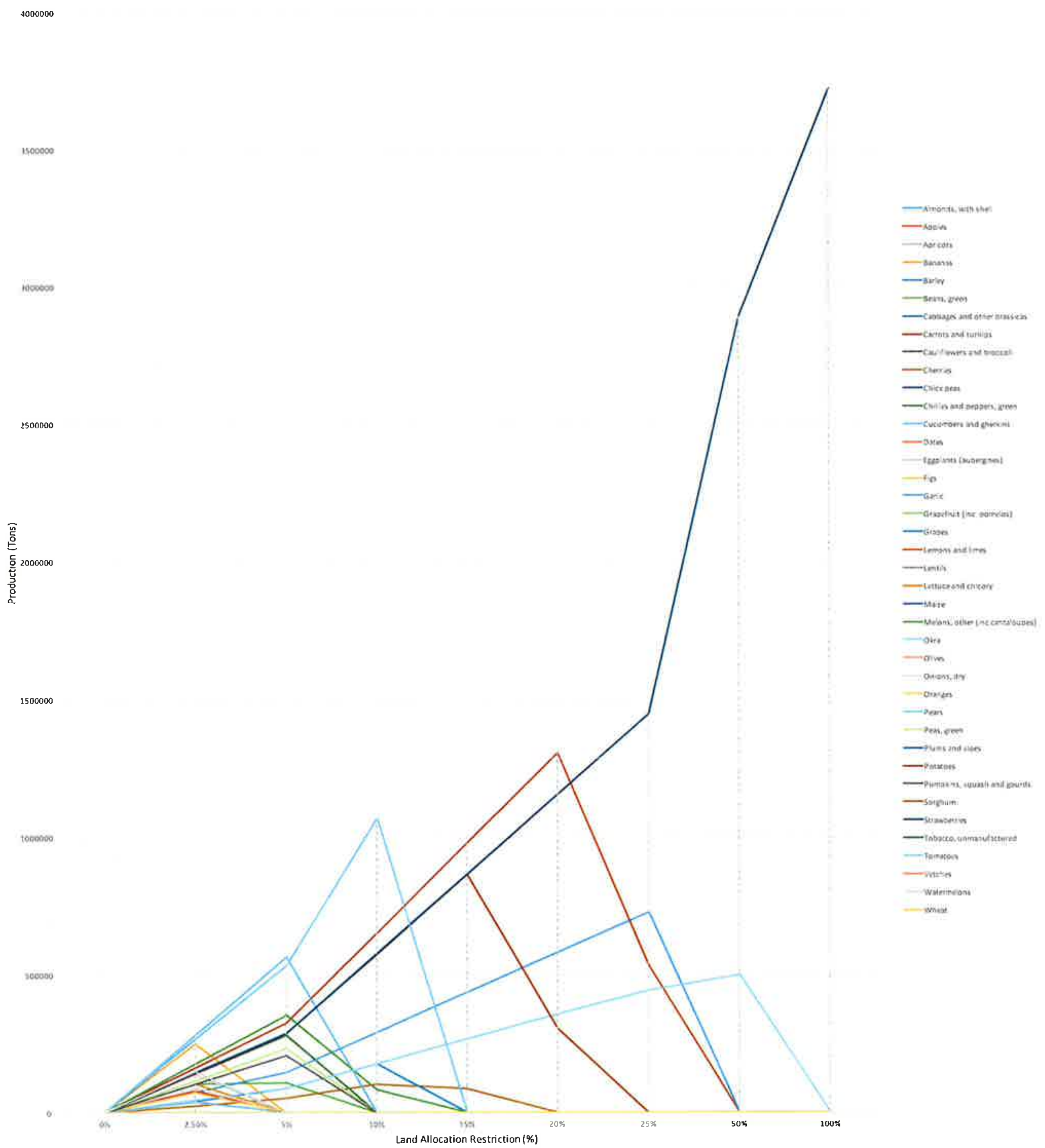


Figure 3: GPV ($) Per Crop Under Land Allocation Restriction Scenarios

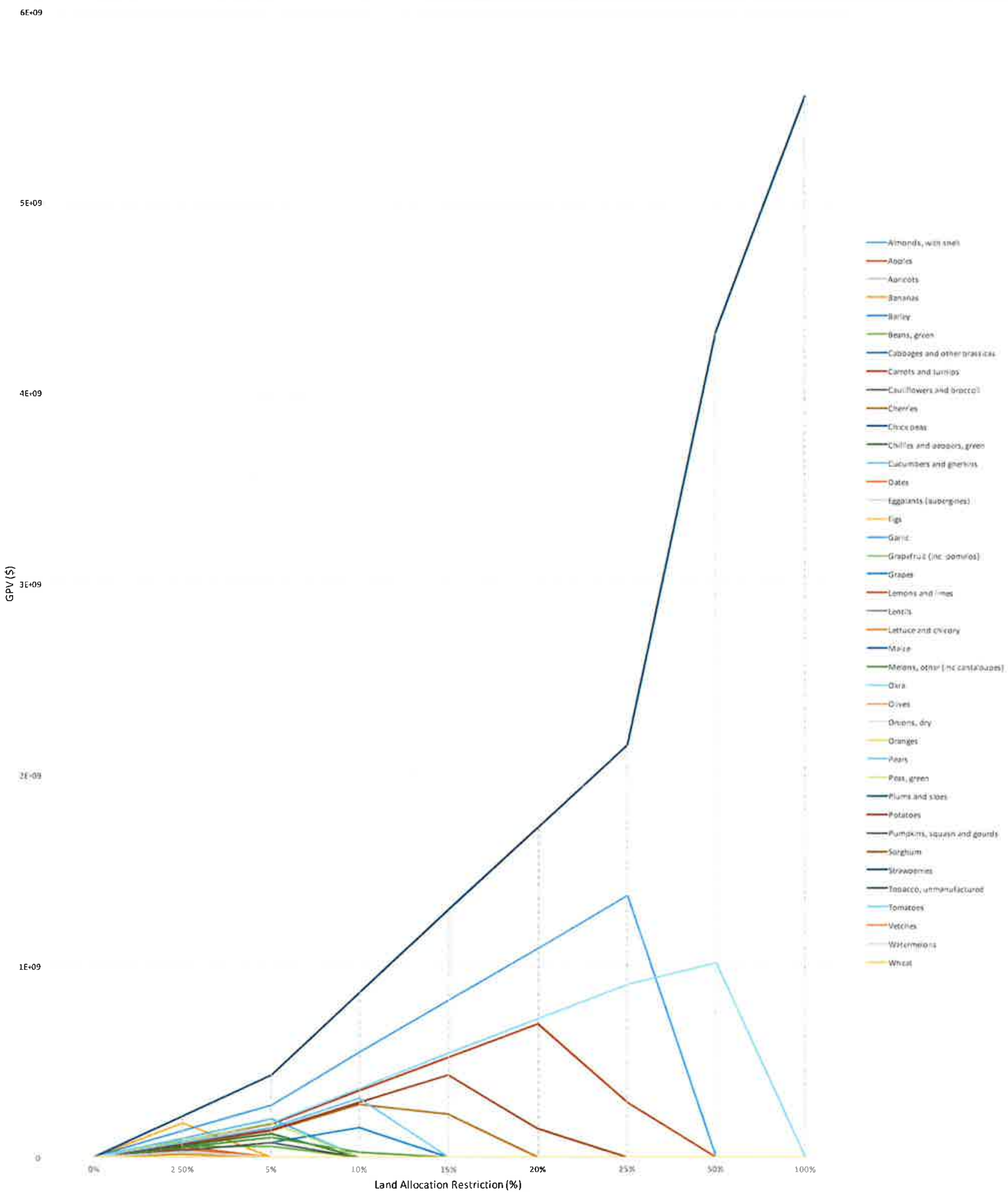


Table 6: Water allocations (m³) under water restriction scenarios

Crop	2.5%	5%	10%	15%	20%	25%	50%	100%
Almonds, with shell	10957847.7	0	0	0	0	0	0	0
Apples	10957847.7	0	0	0	0	0	0	0
Apricots	10957847.7	21915695.4	0	0	0	0	0	0
Bananas	10957847.7	21915695.4	0	0	0	0	0	0
Barley	10957847.7	0	0	0	0	0	0	0
Beans, green	10957847.7	21915695.4	0	0	0	0	0	0
Cabbages and other brassicas	10957847.7	0	0	0	0	0	0	0
Carrots and turnips	10957847.7	21915695.4	43831390.81	65747086.21	87662781.62	109578477	0	0
Cauliflowers and broccoli	10957847.7	0	0	0	0	0	0	0
Cherries	10957847.7	21915695.4	43831390.81	65747086.21	0	0	0	0
Chick peas	10957847.7	0	0	0	0	0	0	0
Chillies and peppers, green	10957847.7	21915695.4	0.061695911	0	0	0	0	0
Cucumbers and gherkins	10957847.7	21915695.4	0	0	0	0	0	0
Dates	10957847.7	0	0	0	0	0	0	0
Eggplants (aubergines)	10957847.7	0	0	0	0	0	0	0
Figs	10957847.7	0	0	0	0	0	0	0
Garlic	10957847.7	21915695.4	43831390.8	65747086.21	87662781.62	109578477	0	0
Grapefruit (inc. pomelos)	10957847.7	0	0	0	0	0	0	0
Grapes	10957847.7	21915695.4	43831390.81	43831390.83	0	0	0	0
Lemons and limes	10957847.7	21915695.4	0	0	0	0	0	0
Lentils	10957847.7	0	0	0	0	0	0	0
Lettuce and chicory	10957847.7	0	0	0	0	0	0	0
Maize	10957847.7	0	0	0	0	0	0	0
Melons, other (inc.cantaloupes)	10957847.7	21915695.4	43831390.81	0	0	0	0	0
Okra	10957847.7	21915695.4	43831390.8	65747086.21	87662781.62	109578477	219156954	0
Olives	10957847.7	0	0	0	0	0	0	0
Onions, dry	10957847.7	21915695.4	0	0	0	0	0	0
Oranges	10957847.7	21915695.4	0	0	0	0	0	0
Pears	10957847.7	21915695.4	0	0	0	0	0	0
Peas, green	10957847.7	21915695.4	43831390.8	0	0	0	0	0
Plums and sloes	10957847.7	0	0	0	0	0	0	0
Potatoes	10957847.7	21915695.4	43831390.81	65747086.21	87662781.62	0	0	0
Pumpkins, squash & gourds	10957847.7	21915695.4	0	0	0	0	0	0
Sorghum	10957847.7	0	0	0	0	0	0	0
Strawberries	10957847.7	21915695.4	43831390.8	65747086.21	87662781.62	109578477	219156954	438313908.1
Tobacco, unmanufactured	10957847.7	0	0	0	0	0	0	0
Tomatoes	10957847.7	21915695.4	43831390.81	0	0	0	0	0
Vetches	10957847.7	0	0	0	0	0	0	0
Watermelons	10957847.7	0	0	0	0	0	0	0
Wheat	10957847.7	0	0	0	0	0	0	0
Water used (m³)	438313908.1	438313908.1	438313908.1	438313908.1	438313908.1	438313908.1	438313908.1	438313908.1
Remaining water	0	0	0	0	0	0	0	0
GPV ($)	1302336528	2070297556	2909235307	3503984973	4001311248	4443272982	5053732823	5556511193

Figure 4: Water (m³) Per Crop Under Water Allocation Restriction Scenarios

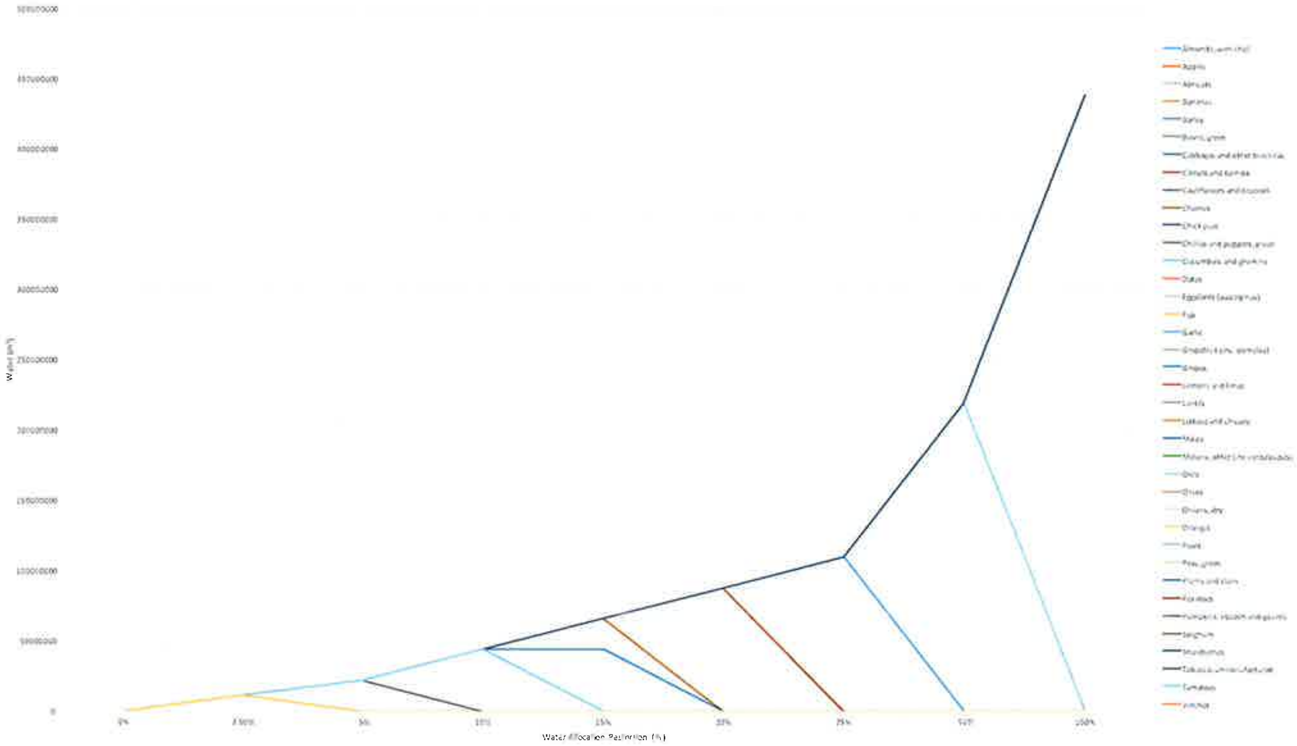


Figure 5: Production (Ton) Per Crop Under Water Allocation Restriction Scenarios

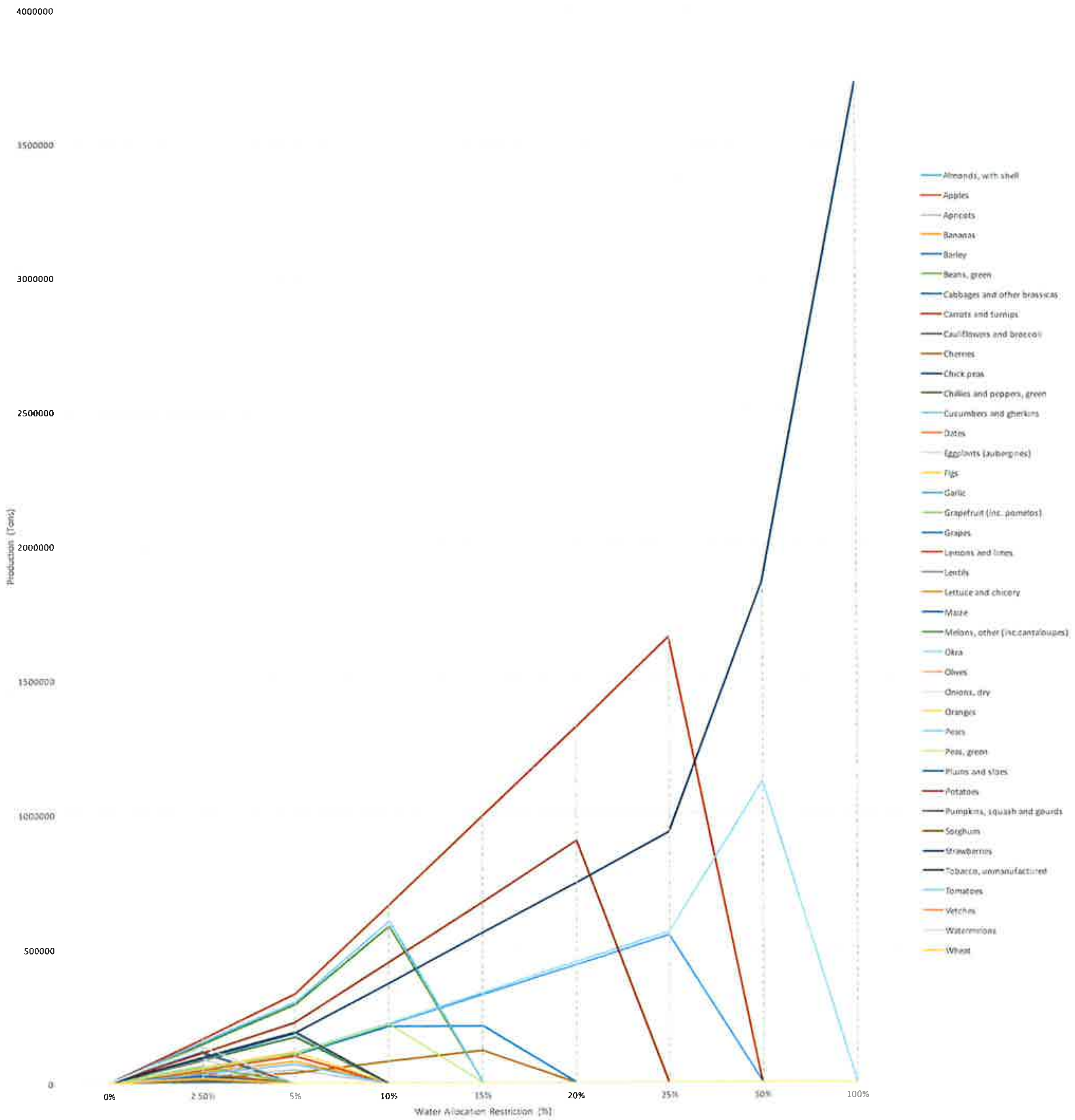


Figure 6: GPV ($) Per Crop Under Water Allocation Restriction Scenarios

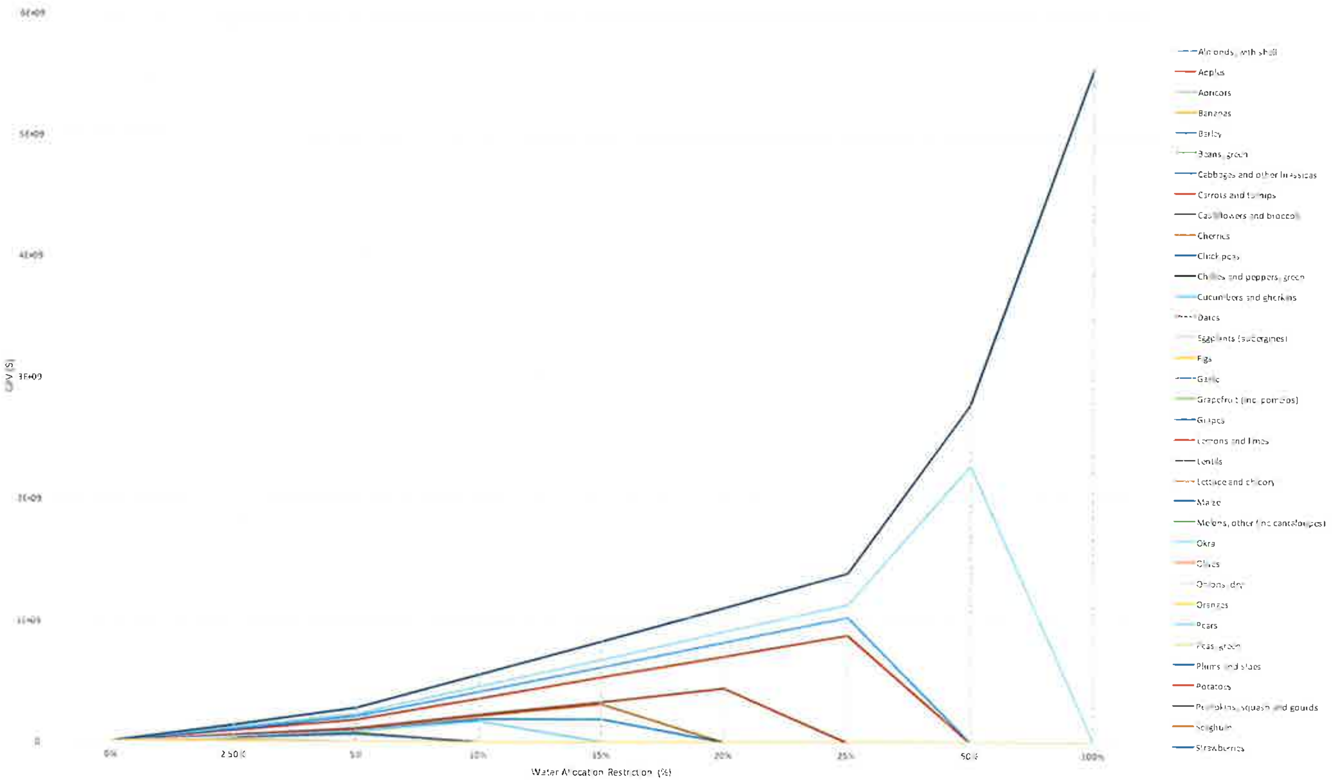
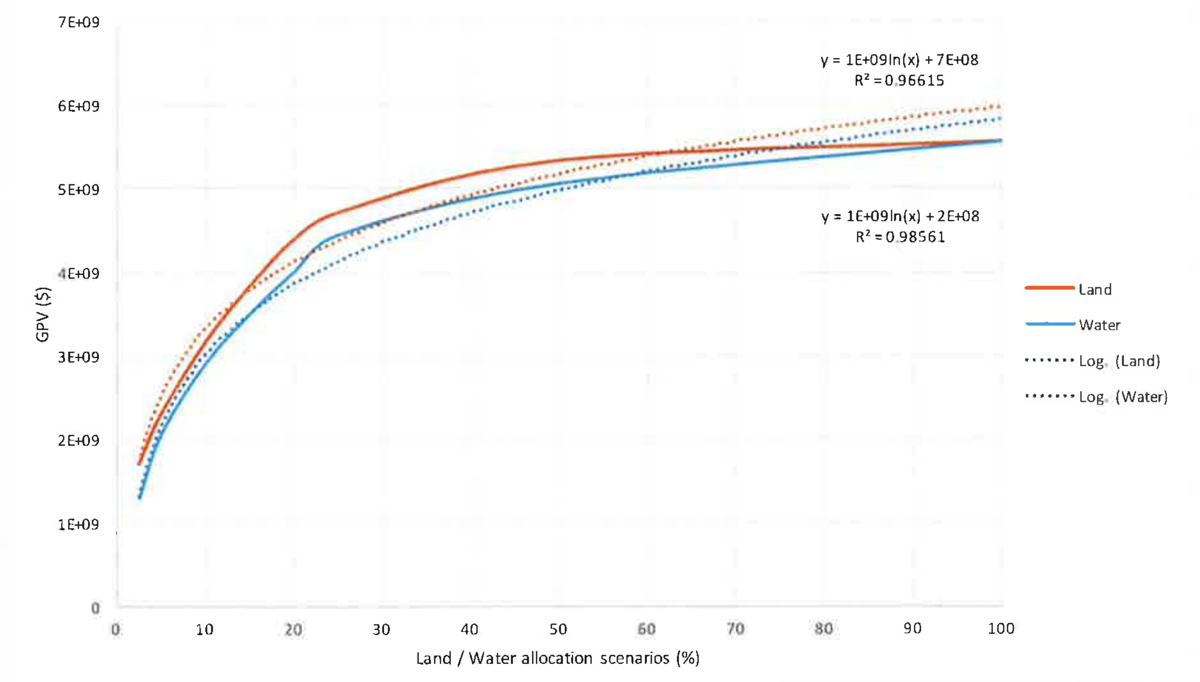


Figure 7: Relationship Between GPV ($) and Land/Water Allocation Restriction Scenarios



Discussion

Optimising GPV with land and water restriction scenarios significantly increases 2013's agricultural GPV (~$886m), even in the least profitable scenarios of land and water constraints of 2.5%, ~$1.7bn and ~$1.3bn respectively. The maximum GPV output is seen in the scenarios where no land and water restriction is made (100%), and we only plant the one crop that is most efficient in terms of land-water allocation and GPV output: strawberries. In that scenario, the GVP is ~$5.6bn, with a production of ~3.7m tons of strawberries as seen in figures 2 and 5, as opposed to 2013's production of 4,955 tons.

A relationship between risk and GPV emerges from the results as seen in figure 7. As risk increases, GPV increases with a logarithmic relationship and high r-squared. Risk increases as land (water) restrictions decrease. Therefore, a 100% restriction, where one crop can occupy 100% of arable land (water) and contribute to 100% of GPV as seen in figures 1-6, reflects maximum level of risk for various reasons, including: market prices continuously shifting, demand continuously shifting, crop diseases, etc. At maximum risk, the scenarios reflect maximum GPV outcome of ~$5.6bn by planting only strawberries. At lowest risk of 2.5% land (water) restriction scenarios, the GPV is at its lowest level, yet production, GPV and and resources are distributed more equally displayed in figures 1-6.

In terms of the limited resources of arable land and water, table 5 indicates that there is remaining arable land available to plant on in every scenario. This indicates that water is the main shortage out of the two constraints, and if the country was able to allocate more water to agricultural irrigation, more crops can be grown on the remaining arable land, resulting in an increased total GPV. The same conclusion can be made when looking at table 6's remaining water, which is equal to 0 in every scenario. Figure 7 also shows that creating land restriction scenarios is always more profitable than creating the same water restriction scenarios.

Taking into account the levels of risk associated with limiting agriculture to a narrow range of plants, and taking into consideration the potential of further water capture and allocation to the agriculture industry, this model shows that the 2.5% and 5% land restriction model is a viable one to follow moving forward. Not only does it increase the current GPV by more than twice its amount, but it also leaves large areas of land that could be used if the country allocates more water to the agriculture industry.

Part two: How can the country of Jordan optimise the SSR (%) of its agriculture industry?

Methodology

In order to answer the second research question, we set up another linear programming model that optimises the SSR given the same two constraints: water and arable land.

The objective function in this case uses the same 40 variables (crops), but the coefficients represent the ratio of demand satisfied per 1 ton production of each crop.

$$Z = \sum_{i=1}^{n} c_i X_i = 0.000233 \text{ almonds} + 0.0000123 \text{ apples} + \dots \text{ (40 variables)}$$

The two constraints remain the same as those in the first research question:

Water constraint: *2730 almonds + 279 apples +...(40 variables) ≤ 481,000,000*
Land constraint: *0.14 almonds + 0.06 apples + ...(40 variables) ≤ 190,304*

Upper bounds for each crop is set as the demand for that crop in 2013. This is because once the production has reached the demand, the SSR = 100%.

Results

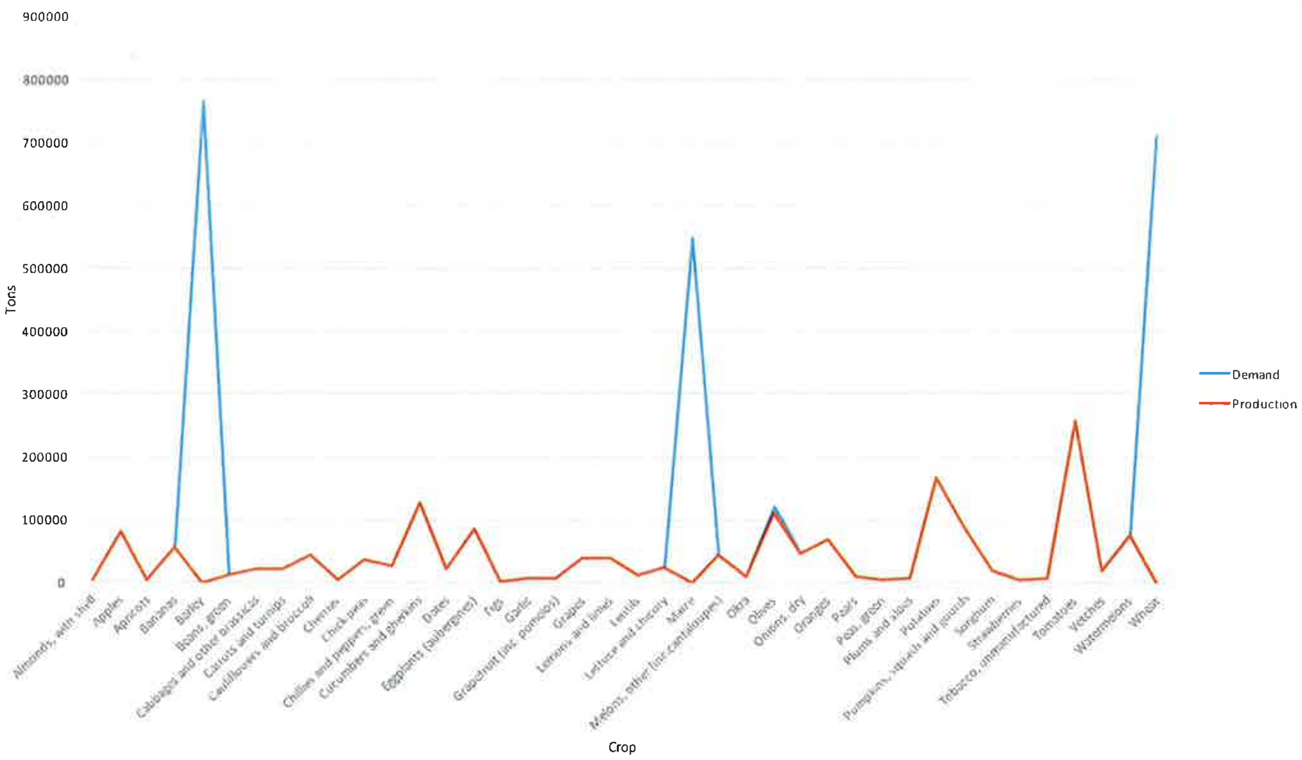
Table 7 displays the results based on optimising the SSR for each crop. The table includes the production (tons), land allocation (Ha), water consumption (m^3), GPV ($) for each crop. The bottom of the table includes the total and remaining land and water, as well as the total GPV.

Figure 8 plots the demand for 2013 against the production based on the SSR optimisation.

Table 7: Optimisation based on SSR

Crop	Demand (Ton)	Production (Ton)	Land (Ha)	Water (m^3)	GPV ($)	SSR (%)
Almonds, with shell	4296.0077	4296.0077	619.4407875	11726135.17	8546422.553	100
Apples	81484.0984	81484.0984	4774.53353	22719591.88	54766363.63	100
Apricots	4053.9606	4053.9606	6261.111316	1769758.122	4662648.194	100
Bananas	55835.9644	55835.9644	1064.669728	14962251.71	40532225.94	100
Barley	763589.212	0	0	0	0	0
Beans, green	10306.0248	10306.0248	464.0493168	1961145.826	5486859.608	100
Cabbages and other brassicas	21255.0136	21255.0136	415.8460304	2018716.172	2403910.749	100
Carrots and turnips	20670.0034	20670.0034	602.1272033	1367196.705	11074457.4	100
Cauliflowers and broccoli	44635.0568	44635.0568	2015.017547	4314960.211	10366640.38	100
Cherries	3461.994	3461.994	623.3559005	1883590.617	9056603.616	100
Chick peas	36461.998	36461.998	40468.36624	51660758.91	17815057.22	100
Chillies and peppers, green	26308.9372	26308.9372	886.5033433	3382192.778	11453663.04	100
Cucumbers and gherkins	126899.0507	126899.0507	2138.259156	15194587.77	44968720.85	100
Dates	20080.0448	20080.0448	3606.718531	15508991.27	16117711.19	100
Eggplants (aubergines)	84711.9253	84711.9253	2919.661141	10401811.19	22454641.05	100
Figs	925.9983	925.9983	192.7918015	1052230.388	872526.7448	100
Garlic	5966.0004	5966.0004	389.4713762	1191940.061	11190858.02	100
Grapefruit (inc. pomelos)	6906.013	6906.013	441.0026312	1185314.922	1798477.667	100
Grapes	38736.0102	38736.0102	4187.586248	7988666.833	34060399.73	100
Lemons and limes	38141.0698	38141.0698	2249.69299	8305843.462	20811002.48	100
Lentils	11289.9939	11289.9939	13769.9645	22494870.28	9717796.332	100
Lettuce and chicory	24941.064	24941.064	742.4703596	2005022.111	3888694.344	100
Maize	548167.0368	0	0	0	0	0
Melons, other (inc.cantaloupes)	42758.0222	42758.0222	1150.64027	3205278.17	12460042.89	100
Okra	8761.9807	8761.9807	937.0000038	1711908.78	17774519	100
Olives	120044.494	109354.6747	53224.31359	111835713.6	103978952.5	91.10
Onions, dry	46969.0245	46969.0245	2471.858767	5496503.123	14467756.84	100
Oranges	68514.9036	68514.9036	4529.851067	13014542.97	35598886.21	100
Pears	8821.012	8821.012	1080.05338	2758704.463	7080385.07	100
Peas, green	3322	3322	135.5697038	670459.328	2560746.835	100
Plums and sloes	5771.0262	5771.0262	714.333162	4267419.95	3656045.466	100
Potatoes	166186.8796	166186.8796	5478.712441	16178359.2	82438150.38	100
Pumpkins, squash & gourds	87091.9341	87091.9341	3951.593411	9925972.24	31426718.8	100
Sorghum	19986.9635	19986.9635	1082.512171	20657374.22	1783351.749	100
Strawberries	3798.993	3798.993	124.9216714	447150.5937	5668533.973	100
Tobacco, unmanufactured	5847	5847	7795.999998	5801159.52	10725291.78	100
Tomatoes	257618.9288	257618.9288	4574.752112	18700248.9	73874955.35	100
Vetches	18170.9144	18170.9144	2772.999994	14502890.01	15752465	100
Watermelons	75831.075	75831.075	2405.42661	6044646.65	14674902.93	100
Wheat	710069.9853	0	0	0	0	0
Total	-	-	181263.178	438313908.1	775967385.5	-
Remaining	-	-	9,041	42,686,092	-	-

Figure 8: Demand and Production (Ton) Per Crop



Discussion

In this linear programming model, an entirely different allocation mix than optimising based on GPV. The model shows that given limited arable land and water resources, and given the demand of the population, the country can self-sustain itself on 36 out of the 40 main crops, sustain 91.1% of one crop (olives), and import 100% of demand for 3 crops: barley, maize and wheat.

Further, by optimising based on SSR, the GPV value is much lower than any optimisation scenario based on GPV. Although it is not surprising, since the optimisation is targeting self-sufficiency rather than dollar value produced, yet ~$776m is nearly half of the lowest GPV value (~$1.3bn based on 2.5% maximum water allocation) in the GPV optimisation model. The GPV is also lower than the 2013 agricultural GPV ~$886m. Therefore, while a self-sustainability optimisation may seem desirable from an environmental standpoint, it proves to be a less viable approach from an economic standpoint.

Conclusion

The models demonstrate great potential in rethinking crop production in Jordan based on different land-water allocations. Due to Jordan being resource-poor and import-dependent, future agricultural production decisions should be based on optimal allocations of resources to produce optimal GPV and/or self-sustainability. Therefore, this study serves as a source for future decision-making in the industry.

Words = 1,987

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