Saudi Journal of Biological Sciences (2016) 23, 92–100

King Saud University

Saudi Journal of Biological Sciences

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ORIGINAL ARTICLE

New approach for determination of an optimum honeybee colony's carrying capacity based on productivity and nectar secretion potential of bee forage species

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Received 5 May 2014; revised 22 September 2014; accepted 27 September 2014
Available online 20 October 2014

KEYWORDS

Honeybee colonies;
Bee forage;
Carrying capacity;
Ziziphus spina-christi;
Acacia tortilis;
Profitability

Abstract The present study was carried out to determine an optimum honeybee colony's carrying capacity of selected valleys dominated by *Ziziphus spina-christi* and *Acacia tortilis* in the Al-Baha region, Kingdom of Saudi Arabia. The study was conducted based on the assessment of the number of colonies kept, their productivities and the existing productive bee forage resources in the target valleys with its economic implication. In the existing beekeeping practice, the average number of managed honeybee colonies introduced per square kilometer was 530 and 317 during the flowering period of *Z. spina-christi* and *A. tortilis*, respectively. Furthermore, the overall ratios of productive bee forage plants to the number of honeybee colonies introduced were 0.55 and 11.12 to *Ziziphus* trees and *A. tortilis* shrubs respectively. In the existing situation the average honey production potential of 5.21 and 0.34 kg was recorded per *Ziziphus* and *A. tortilis* plants per flowering season, respectively. The present study, revealed that the number of honeybee colonies introduced in relation to the existing bee forage potential was extremely overcrowding which is beyond the carrying capacity of bee forage resources in selected valleys and it has been observed to affect the productivities and subsequent profitability of beekeeping. The study infers that, by keeping the optimum honeybee colony's carrying capacity of valleys (88 traditional hives/km^2 or 54 Langstroth hives/km^2

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Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.sjbs.2014.09.020
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in *Ziziphus* field and 72 traditional hives/km^2 or 44 Langstroth hives/km^2 in *A. tortilis* field), profitability of beekeeping can be boosted up to 130.39% and 207.98% during *Z. spina-christi* and *A. tortilis*, flowering seasons, respectively.

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1. Introduction

Beekeeping is one of the most important economic activities for rural communities in Saudi Arabia, where approximately 5000 beekeepers maintain more than one million honeybee colonies and produce approximately 9000 tons of honey annually (Al-Ghamdi, 2007). Despite the rapid development of the subsector in the country, there are still many challenges and constraints facing the beekeeping industry (Al-Ghamdi and Nuru, 2013b). Among these, overcoming of the seasonal shortage of bee forage is one of the critical challenges to the development of this subsector.

In most cases, success in beekeeping depends on the availability of sufficient bee forage in terms of both quality and quantity of nectar and pollen grains. Hence, beekeeping is more dependent on the existing natural resource conditions of an area than any other livestock activities. In areas, where beekeeping is not suitable, other improved management skills and advanced technologies alone cannot make beekeeping successful. For this reason, availability of adequate bee forage is considered to be one of the most important elements in beekeeping industry. In many areas of the Kingdom, bees and beekeepers suffer from seasonal drought, which causes a shortage of bee forage (Al-Ghamdi and Nuru, 2013b; Alqarni et al., 2011). These conditions drive many beekeepers to move their colonies from one area to another in search of better nectar and/or pollen sources and to avoid severe weather conditions (Alqarni et al., 2011). However, this often leads to a concentration of a large number of bee colonies (owned by a single or multiple beekeepers) in limited areas, regardless of honeybee colony population density and the actual carrying capacity of the areas (Al-Ghamdi and Nuru, 2013a). Beekeepers concentrate on only some areas in search of a few particular species of plants that provide the most desired and expensive type of honey (Al-Ghamdi, 2005). In this regard, there is no directive to guide or determine the number of colonies to be placed per unit area, nor has it set out the minimum distances between two adjacent apiaries to minimize competition caused by the overlapping of foraging ranges and subsequent declines of productivity of colonies. As a result overcrowding and resource completion are very intense. Some studies suggested the minimum distance between two commercial apiaries to be 1.5–2 km (Hagler et al., 2011).

The occurrence of imbalances between the number of bee colonies and the important bee forage areas and the subsequent decline in productivity per colony has been well documented (Khanbash, 2001). Recent statistical data indicate, the number of bee colonies in the country has significantly increased some fourfold during the last decade, from 270,000 honeybee colonies in 1995 to more than one million in 2007 (Al-Ghamdi, 2007), while foraging areas have remained approximately unexpanded. On the other hand, a significant decline was reported in the average annual yield of honey per colony from 15 kg/colony in 1997 to about 8 kg/colony in 2007 (Al-Ghamdi, 2007). A recent study revealed the average annual yield of honey per colony declined to 3.7 kg/traditional hive and 6.6 kg/Langstroth hive in 2012 (Nuru et al., 2014), which is a great challenge for beekeeping industry. This decline in honey yield per colony can be attributed to many factors, the most important of which are scarcity of bee forage and overstocking honeybee colonies above the carrying capacity of available forage area (Al-Ghamdi, 2005). As a result, beekeepers are subjected to low financial returns from their honeybee colonies (Khanbash, 2001) and are unaware of how to increase the productivities of their colonies through optimizing the carrying capacity of bee forage areas. Therefore, assessing the optimum carrying capacity of major valleys is very crucial to guide beekeepers. Plant and flower density, nectar secretion potential and nectar sugar concentration were considered for determination of carrying capacity. In this study, the optimum carrying capacity was defined as the number of honeybee colonies on a given number of flowering plants per given area or places without negatively affecting honey production potential of individual colonies. The purposes of the present study were: (1) to assess the spatial and temporal distribution of selected bee forage plants and density of honey bee colonies along potential valleys, (2) to determine optimum colony carrying capacity of valleys based on yield potential and distribution of bee forage plants, and (3) to indicate the financial implications of bee colony overstocking in productivity and profitability of beekeeping.

2. Materials and methods

The study area is located in the Southwestern parts of Saudi Arabia, in some important valleys of the Al-Baha region. The study was conducted in two agro-ecologically different locations representing, midland and lowland areas. The midland valleys are those located at about 40 km North-East of Baljurashi Town (Barha-Magama, Wable and Kahla valleys), at a geographic location of 19°58″52′–20°06″41′N and 41°43’’52′–41°45’’18′E and at an altitudinal range of 1200–1700 m above sea level while the lowlands are located at 30–40 km Southwest of Buljurashi Town, at valleys Alkhaitan, Neera, Batat and Soqama having 19°43″18′–19°46″21′N and 41°38″52′–41°40″04′E geographical location, and altitudes ranging between 400 and 1000 m above sea level. In the region, *Ziziphus spina-christi* (Sidr) and *A. tortilis* (Sumra) are the major honey source plants that flower in different seasons, hence, were of major interest to address our objectives. The total land area of the study sites was about 25.2 km^2. Moreover the areas are intensively used by seasonal migratory beekeepers to place thousands of honeybee colonies for honey production during the flowering of the target bee forage species.

2.1. Assessment of *Z. spina-christi* trees and *A. tortilis* shrubs and density of honeybee colonies introduced during the flowering period of the plants

The assessment on *Z. spina-christi* was conducted between September and November 2012 during the main flowering season of the plant in five selected valleys with better potential in honey production (Alkhaitan, Baraha-Magamaa, Wable, Kahla and Neera valleys). The status of all individual trees was recorded from field observation using Trimble GPS in the actual location of trees, which includes flowering condition of individual trees and grouped as plants with massive flowers (productive) and plants with no flowers (non productive).

The assessment on *A. tortilis* was conducted between March and April, 2013 during the main flowering season of two selected valleys (Bata and Soqama) with better potential in honey production. However, the method of *A. tortilis* assessment was limited to sampling plots due to high population density of shrubs rather than recording all trees in the case of *Ziziphus*. Therefore, a total of 18 plots (2500 m^2 each) were sampled to assess the number of plants per plot, tree height, canopy height, canopy diameter, canopy volume, number of flowers per metric cube, amount of nectar secreted per flower. Then these data were extrapolated to estimate the total number of *A. tortilis* and the amount of honey to be harvested per selected valley. Furthermore, the locations of apiaries, number of colonies per apiary, honeybee races and types of beehives used were recorded using Trimble GPS so that distance between apiaries can be traced back.

2.2. Optimum honey yield expected

Optimum honey yield expected from valleys was considered as the amount of honey yield to be harvested based on nectar secretion potential of the selected bee forage species. Nectar secretion of selected forage species was recorded as trees/shrubs with massive flowers during flowering season. Consequently, the optimum honey yield expected was estimated as: total number of productive trees with massive flowers multiplied by honey productivity potential of the target bee plant (*Z. spina-christi* or *A. tortilis*) and divided by two. The rationality behind dividing the honey productivity potential by two was to consider the assumption that for every 1 kg of harvestable honey, bee colonies may consume 1 kg of honey to fulfill nutrient requirements of maintenance and reproduction.

2.3. Current honey yield

The current honey yield was defined as the average amount of honey that can be harvested from traditional and box hives in the existing honeybee colony density. The average productivity of traditional and box hives was 1.25 kg and 2.26 kg per harvest, respectively (Nuru et al., 2014). Using this baseline information the current honey yield from all the studied valleys was estimated as follows:

$$\begin{aligned}&\text{Total current honey yield in kg}\\&\quad = \text{number of traditional hives} * 1.25\text{ kg}\\&\qquad + \text{number of Langstroth hives} * 2.26\text{ kg per harvest}\end{aligned}$$

Then the expected honey yield difference (kg) = Optimum honey yield expected − current honey yield.

2.4. Optimum colony carrying capacity determination of valleys based on honey yield potential and bee plant density

This study was conducted to determine the optimum carrying capacity of valleys and estimate the honey production potential of honeybee colonies from seven selected valleys in the Al-Baha region. Optimum carrying capacity estimation is crucial in the study area, where overcrowding of honeybee colonies is very intense and frequently observed throughout valleys for honey production.

In order to determine the optimum carrying capacity of valleys, the following assumptions were made: Honey that can be consumed by colonies for their energy requirement and brood rearing. In Europe, a normal-sized colony consumes approximately 60–202 kg of honey per year (Seeley et al., 1991). In turn, well managed hive produces between 60 and 200 kg of honey per year (Chaudhary, 2009). Based on this rough estimation and assuming that all factors remain constant, to harvest 1 kg of surplus honey, the colony has to consume a further 1 kg of honey for survival, brood rearing, as fuel energy to foragers. Based on this requirement 2 kg of honey will be required in order to harvest 1 kg of honey and 1 kg of honey for colony maintenance. In Saudi Arabian condition well managed colonies in traditional and Langstroth hives introduced to areas with adequate floral resources can produce 4.36 and 7.14 kg of honey per harvest respectively (Nuru et al., 2014). Therefore, to obtain optimum yield of (4.36) kg from traditional hives a total of 8.72 kg of honey is needed including colony consumption. As a result, the optimum number of traditional hives per valley has to be limited and can be calculated as follows:

$$\begin{aligned}&\text{Optimum number of traditional hives}\\&\quad = \text{Expected honey yield per valley divided by 8.72.}\end{aligned}$$

To optimize the productivity of Langstroth hives up to 7.14 kg/colony a total of 14.28 kg of honey will be needed per colony per season. Hence, the optimum number of Langstroth hives per valley/per flowering season of specific honey source plant, has been calculated as follows: Optimum number of Langstroth hives = Expected honey yield per valley divided by 14.28

2.5. Financial implication of overcrowding

In order to calculate cost–benefit analysis, major cost of production for current beekeeping practice and optimum carrying capacity were considered. Hence, total cost of hives, honeybee colony for apiary establishment and labor was considered to compare the difference in the production cost and final profit, assuming that other factors more or less will remain similar in both the existing beekeeping practice and beekeeping with optimum colony carrying capacity of valleys.

Accordingly, the price of hives (both traditional and Langstroth hives) obtained from carpenters' workshops and honeybee colonies (local and imported) was assessed in the study area. In the region, traditional and box hives are estimated

Table 1 Density of colonies, optimum and current honey yield (kg) of *Ziziphus spina-christi* in different valleys.

Name of valley	Productive trees (A)	Number of apiaries	Number of colonies (B)	Traditional hives (C)	Langstroth hives (D)	Ratio of trees to colonies	Optimum honey yield expected (5.21 kg * A)/2	Current honey yield (1.25 * C + 2.26 * D)	Distance between apiaries (m)
Alkhaitan	1695	21	3587	3563	24	0.47	4415	4508	495
Baraha-Magamaa	1007	36	1778	799	979	0.57	2623	3211	250
Wable	695	29	1262	585	677	0.55	1810	2261	350
Kahla	571	10	1004	750	254	0.57	1487	1512	295
Neera	725	20	847	118	729	0.86	1889	1795	510
Total	4693	116	8478	5815	2663	0.55	12,225	13,287	380

Note: Average productivity data for traditional (1.25 kg) and Langstroth hives (2.26 kg) per harvest were adopted from honey production system study (unpublished). The value 5.21 kg represents honey production potential of productive *Ziziphus spina-christi* tree per flowering season.

to serve for five and eight years respectively. Further, three honey flow seasons are expected in migratory beekeeping practice (Nuru et al., 2014). Hence, the cost of production was calculated for a single honey flow season only for the flowering periods of selected honey source plants (*Ziziphus* and *A. tortilis*). Finally, the selling price for a kg of *Ziziphus* (Sidr) and *A. tortilis* (Sumra) honey in local markets was assessed in the study area. Therefore, cost–benefit of beekeeping was calculated using the following formula (Onwumere et al., 2012; Folayan and Bifarin, 2013).

$$\mathrm{NI} = \mathrm{GR} - \mathrm{TC}$$

where: NI = Net Income, GR = Gross Return, TC = Total production Cost.

$$\mathrm{TC} = \mathrm{TVC} + \mathrm{TFC}$$

where: TVC = Total Variable Cost, TFC = Total Fixed Cost.

The gross return represents the income from honey sales while the total production costs (TVC + TFC) represent direct purchases for the beekeeping activities which include fixed costs.

Partial budget analysis was performed in order to evaluate the profitability of optimum carrying capacity in comparison to the existing beekeeping practice.

3. Results

3.1. *Z. spina-christi*

3.1.1. *Optimum honey yield expected from Ziziphus*

Based on nectar secretion amount and dynamics study, the average honey production potential of *Ziziphus* trees was calculated to be 5.21 kg per tree per flowering season (Nuru et al., 2012, 2013a). Hence, productive trees with massive flowers assumed to produce 5.21 kg of honey per season. Consequently, we had a total number of 4693 trees with massive flowers (Table 1). Accordingly, the optimum honey yield expected from all valleys studied was estimated to be 12,225 kg of honey per season. Therefore, the expected productivity of individual colony was 1.44 kg of honey per harvest which was much lower than optimum productivity potential per hive. However, the productivity of traditional and box hives can be maximized up to 4.36 and 7.14 kg per harvest respectively (Nuru et al., 2014). The density of *Z. spina-christi* and optimum honey yield expected from *Ziziphus* are presented in Table 1.

3.1.2. *Current honey yield from Ziziphus with the existing honeybee colony density*

The density of the existing honeybee colony and current honey yield are presented in Table 1. Based on our extensive honey production system survey result in the Kingdom of Saudi Arabia and practical observation the average productivity of traditional hives and Langstroth hives was 1.25 kg and 2.26 kg per harvest respectively. Using this baseline information the total current honey yield from all the valleys studied was estimated to be 13,287 kg of honey per season. Then the expected honey yield difference was 1062 kg of honey lower than current honey yield per season.

3.1.3. *Optimum carrying capacity of valleys – Z. spina-christi in selected valleys*

To optimize productivity of traditional hives up to 4.36 kg a total of 8.72 kg of honey will be needed. As a result, the optimum number of traditional hives per valley was calculated as: Optimum number of traditional hives = Optimum honey yield expected per valley divided by 8.72 = 12,225.27/8.72 = 1402 traditional hives. Similarly, to increase productivity of Langstroth hives up to 7.14 kg a total of 14.28 kg of honey will be needed per colony per season. Hence, the optimum number of Langstroth hives per valley was calculated as: Optimum number of Langstroth hives = Optimum honey yield expected per valley divided by 14.28 = 12,225.27/14.28 = 856 Langstroth hives. The current number of colonies introduced to the valleys during the flowering period of *Ziziphus* was 6.05- and 9.90-folds more than the optimum number of colonies in traditional and Langstroth hives, respectively (Table 2).

3.2. *A. tortilis*

3.2.1. *Optimum honey yield expected from A. tortilis*

Based on nectar study the average honey production potential of *A. tortilis* trees was calculated to be 0.34 kg per tree per flowering season (Nuru et al., 2013a). Then, it was assumed productive trees with massive flowers will produce 0.34 kg of honey per tree per season. Hence, a total number of 35,300

Table 2 Optimum carrying capacity of Alkhaitan, Baraha-Magamaa, Wable, Kahla and Neera valleys.

Name of valley	Optimum honey yield expected (kg)	Introduced number of hives			Optimum number of hives to be introduced		Area of Wadi in square km
		Sum of colonies	Traditional hives	Langstroth hives	Traditional hives	Langstroth hives	
Alkhaitan	4415	3587 (598)	3563	24	506(84)	309 (52)	6.0
Baraha-Magamaa	2623	1778 (296)	799	979	301(57)	184(35)	5.3
Wable	1810	1262 (1262)	585	677	208 (208)	127(127)	1.0
Kahla	1487	1004 (1004)	750	254	171 (190)	104(116)	0.9
Neera	1889	847 (282)	118	729	217 (87)	132 (53)	2.5
Total	12,225	8478 (530)	5815	2663	1402 (88)	856 (54)	16

Note: Sum of colonies was introduced to each valley, however, the values in optimum number of hives to be introduced are estimated either for traditional or Langstroth hives. Values in the bracket indicate the number of hives introduced or to be introduced per square km in each valley. Values for number of hives and honey yield were taken to the nearest full digit.

Table 3 Density of colonies, optimum and current honey yield (kg) of *Acacia tortilis* in different valleys.

Name of valley	Productive trees (A)	Number of apiaries	Number of colonies (B)	Traditional hives (C)	Langstroth hives (D)	Ratio of trees to colonies	Optimum honey yield expected(0.34 kg * A) /2	Current honey yield (1.25 * C + 2.26 * D)	Distance between apiaries (m)
Batat	30,698	8	2404	2321	83	12.77	5219	3089	595
Soqama	4602	5	770	510	260	5.98	782	1225	800
Total	35,300	13	3174	2831	343	11.12	6001	4314	698

Note: Average productivity data for traditional (1.25 kg) and Langstroth hives (2.26 kg) per harvest were adopted from honey production system study (Nuru et al., unpublished). The value 0.34 kg represents honey production potential of productive *Acacia tortilis* tree per flowering season.

trees were found with massive flowers (Table 2). Accordingly, the total optimum honey yield expected from all valleys studied is estimated to be 6001 kg of honey per season. Therefore, the expected productivity of the individual colony was1.89 kg of honey per harvest which is much lower than the productivity potential per hive. The productivity of traditional and Langstroth hives can be maximized up to 4.36 and 7.14 kg of honey per harvest, respectively (Nuru et al., 2014).The density of *A. tortilis* shrubs and optimum honey yield expected from *A. tortilis* are presented in Table 3.

3.2.2. Current honey yield from A. tortilis with the existing honeybee colony density

Our honey survey result in the Kingdom of Saudi Arabia and practical observation reveal the average productivity of traditional and Langstroth hives was 1.25 kg and 2.26 kg per harvest, respectively. Using this baseline information the total current honey yield from all the valleys studied was estimated to be 4314 kg of honey per flowering season of *A. tortilis*. Then the expected honey yield difference was1687 kg of honey per season. The density of honeybee colony, *A. tortilis* shrubs and current honey yield are presented in Table 3.

3.2.3. Optimum carrying capacity of valleys – A. tortilis in selected valleys

To increase productivity of traditional hives up to 4.36 kg a total of 8.72 kg of honey will be needed. As a result, the optimum number of traditional hives per valley was calculated to be 688 traditional hives (Table 4). Similarly, to increase productivity of Langstroth hives up to 7.14 kg a total of 14.28 kg of honey will be needed per colony per season. Hence, the optimum number of Langstroth hives per valley was calculated to be 420.24 Langstroth hives (Table 4).The current number of colonies introduced to the valleys during the flowering period of *A. tortilis* was 4.62- and 7.56-folds more than the optimum number of colonies in traditional and Langstroth hives (Table 4).

3.3. Cost–benefit analysis of optimum carrying capacity

List of items, average price and minimum input price to establish new colony are presented in Table 5. Moreover, Tables 6 and 7 show the partial budget analysis of optimum carrying capacity options in comparison to the existing beekeeping practice.

4. Discussion

In the present study, the average number of managed honeybee colonies introduced per square kilometer was 530 and 317 during the flowering period of *Z. spina-christi* and *A. tortilis*, respectively (Tables 2 and 4), which reveals the occurrence of extremely overcrowding of colonies beyond the carrying capacity of the existing bee forage resources compared to previous reports in other parts of the world. Semkiw and Shubida (2010) reported 3.68 managed honeybee colonies per square kilometer in Poland condition. Similarly, the natural density of wild or feral honeybee colonies was reported to be 4.2 and 6 per square kilometer in Botswana (Mcnally and Schneider, 1996) and Mexico (Ratnieks et al., 1991), respectively.

Table 4 Optimum carrying capacity of Batat and Soqama valleys dominantly covered by *A. tortilis*.

Name of valley	Optimum honey yield expected (kg)	Introduced number of hives			Optimum number of hives to be introduced		Area of Wadi in square km
		Sum of colonies	Traditional hives	Langstroth hives	Traditional hives	Langstroth hives	
Batat	5219	2404 (301)	2321	83	598 (75)	366 (45)	8.1
Soqama	782	770 (385)	510	260	90 (45)	55 (39)	1.4
Total	6001	3174 (334)	2831	343	688 (72)	420 (44)	9.5

Note: Sum of colonies was introduced to each valley, however, the values in optimum number of hives to be introduced are estimated either for traditional or Langstroth hives. Values in the bracket indicate number of hives introduced or to be introduced per square km in each valley.

Table 5 Input price (SAR).

Items	Average price in SAR	Input price to establish new colony
Langstroth hive manufactured in Al-Baha	65	65
Traditional manufactured (Shomrani)	60	60
Frame (each)	4	40
Bees wax foundation (each)	2.8	28
Local honeybee colony	500	500
Package bees	120	240
Total price to establish Langstroth hive with local bees		633
Total price to establish Langstroth hive with package bees		373
Total price to establish local hive colony with local bees		560
Total price to establish local hive colony with package bees		300

Table 6 Partial budget for optimum carrying capacity conditions compared to the existing beekeeping practice in *Ziziphus* trees valleys.

	Optimum carrying capacity with traditional hives			Optimum carrying capacity with improved box hives		
Valley	Advantages Reduced costs (SAR)	Disadvantages Added costs (SAR)		Advantages Reduced costs (SAR)	Disadvantages Added costs (SAR)	
Alkhaitan	29,210	0		30,868	0	
Bar-Magm	13,558	0		14,350	0	
Wable	13,213	0		13,915	0	
Kahla	23,541	0		25,118	0	
Neera	11,531	0		12,599	0	
Average	18,211	0		19,370	0	
	Added returns (SAR)	Reduced returns (SAR)		Added returns (SAR)	Reduced returns (SAR)	
Alkhaitan	0	1293		0	1293	
Bar-Magm	0	4772		0	4772	
Wable	0	4544		0	4544	
Kahla	0	717		0	717	
Neera	1372	0		1372	0	
Average	274	2265		274	2265	
	Total positive impacts (SAR)	Total negative impacts (SAR)	Additional income (SAR)	Total positive impacts (SAR)	Total negative impacts (SAR)	Additional income (SAR)
Alkhaitan	29,210	1293	27,917	30,868	1293	29,575
Baraha-Magmaa	13,558	4772	8786	14,350	4772	9578
Wable	13,213	4544	8669	13,915	4544	9371
Kahla	23,541	717	22,824	25,118	717	24,401
Neera	12,903	0	12,903	13,971	0	13,971
Average	18,485	2265	16,220	19,644	2265	17,379

Note: Additional income = Total positive impacts minus total negative impacts. Bar-Magm mean Baraha-Magmaa valley.

Table 7 Partial budget for optimum carrying capacity conditions compared to the existing beekeeping practice in *Acacia tortilis* valleys.

	Optimum carrying capacity with traditional hives			Optimum carrying capacity with improved box hives		
Valley	Advantages Reduced costs (SAR)	Disadvantages Added costs (SAR)		Advantages Reduced costs (SAR)	Disadvantages Added costs (SAR)	
Betat	40,604	0		45,771	0	
Soqama	29,729	0		31,109	0	
Average	35,166	0		38,440	0	
	Added returns (SAR)	Reduced returns (SAR)		Added returns (SAR)	Reduced returns (SAR)	
Betat	62,353	0		62,353	0	
Soqama	0	20,740		0	20,740	
Average	31,177	10,370		31,177	10,370	
	Total positive impacts (SAR)	Total negative impacts (SAR)	Additional income (SAR)	Total positive impacts (SAR)	Total negative impacts (SAR)	Additional income (SAR)
Batat	102,957	0	102,957	108,124	0	108,124
Soqama	29,729	20,740	8989	31,109	20,740	10,369
Average	66,343	10,370	55,973	69,617	10,370	59,247

Note: Additional income = Total positive impacts minus total negative impacts.

In addition, a relatively high density of wild or feral colonies which ranges between 12.4 and 17.6 per square kilometer was reported in the African dry highland savannas of South Africa (Moritz et al., 2007), and Texas (Baum et al., 2005).

The overall ratio of productive *Ziziphus* trees and *A. tortilis* to the number of colonies introduced in the valleys was 0.55 and 11.12 with an average honey production potential of 5.21 and 0.34 kg per tree per flowering season, respectively. Consequently, there was a high competition for nectar and pollen resources in the study valleys. Studies reported that honeybees are threatened by overpopulation which is caused by limited resources that can support a certain number of honeybee colonies only (Esteves et al., 2010). As a result, the amount of honey yield being obtained per honey flow season is low compared to the potential of the area with optimum colony size conditions (Tables 6 and 7). This could be due to the fact that, as the number of colonies increases the amount of nectar source consumed by a large number of colonies for survival is high. Beekeeping industry has experienced a rapid honey productivity reduction in the Kingdom of Saudi Arabia due to shortage of floral resources (Al-Ghamdi, 2007; Nuru et al., 2014). Furthermore, the strength of colony could be negatively affected by overcrowding due to a high floral resource competition during flowering season of both plant species. The strength of honeybee colonies depends largely on the availability of nectar and pollen (Esteves et al., 2010).

The present study showed that productivity of colonies can be improved by maintaining the optimum honeybee colony size that matches with the carrying capacity of specific apiary sites (Tables 2 and 4). Optimum distribution of honeybee colonies minimizes overpopulation with consideration of the available honeybee plants within the maximum flight distance of the bees (Esteves et al., 2010). The overall average distance between apiaries in *Ziziphus* and *A. tortilis* dominated valleys was 380 m and 698 m respectively, which is much less than the optimum recommended distance of 1.5–2 km between two apiaries (Hagler et al., 2011). This indicates the occurrences of resource competition among apiaries and colonies within apiaries (Tables 1 and 3).

Determining the optimum distance between apiaries could minimize floral resource competition. Hagler et al., 2011 reported that honey bees can forage up to 5983 m from their apiaries. However, on average honeybees tend to visit within 800 m from their apiary if attractive floral resources are available (Hagler et al., 2011), and honey yield per hive almost can be doubled within 1 km from the forest compared to hives placed about 3 km from the forest (Sande et al., 2009). In the present study, therefore, a minimum of 1 km foraging distance between apiaries was estimated to avoid resource competition and maximize honey productivity per colony while calculating the optimum number of honeybee colonies. Foraging is the act of honeybees fetching food, nectar and pollen from flowers scattered around their beehive in order to feed the colony (Adeva, 2012). Previous studies show deforestation of bee forage plants at alarming rates with very less effort of conservation and rehabilitation (Nuru et al., 2013b). Honeybee population can be limited with loss and fragmentation of forage habitats as well as extreme seasonality in the flowering phenology of plants (Keasar and Shmida, 2009). However, this can be improved by planting bee forage plants in forests, parks, and along roadsides (Keasar and Shmida, 2009), consisting of diverse native and non-native flower rich plantings (Decourtye et al., 2010).

In the case of *Ziziphus*, honey production potential of selected valleys was 7.99% lower than the current honey yield. Reason to harvest a higher current honey yield beyond the area potential for specific plants could be that beekeepers established their honeybee colonies in other potential areas with pollen and nectar sources prior to *Ziziphus* flowering season. Usually beekeepers developed this kind of practice to strengthen their colonies in providing better pollen sources as well as some nectar sources before introducing them to *Ziziphus* flowers, which is mainly a nectar source. In addition, if colonies are well maintained, given sugar syrup and have considerable store, the fresh nectar collected can be stored into honey. Apart from that, there were some co-flowering plants (e.g. *Acacia etbaica* in Baraha-Magama and Wable valleys, *Acacia asak* in Alkhaitan valley) during *Ziziphus* honey flow season. Hence, the honey yield potential in *Ziziphus* areas was expected to be even more than our estimation.

Nevertheless, if an optimum number of colonies are kept, the honey production of selected valleys with *A. tortilis* (Sumra) can be increased by 39.11% than the current production. The reason to harvest lower honey yield in current production below the area's potential could include lack of diverse nectar and pollen sources within the areas and higher consumption of honey to overcome winter season, survival, brood rearing and flight energy prior to *A. tortilis* flowering season. Hence, honeybee colonies could be introduced to *A. tortilis* dominated valleys with no or very little stored resources in the hive which probably increased the rate of honey consumption for their own energy needs and provisioning of the larvae. This is supported by other studies as honeybees consume a certain amount of honey for survival, brood rearing (Seeley et al., 1991), as flight energy (Nuru et al., 2012) and supporting other insects dependent on nectar feeding.

The partial budgeting reveals adopting optimum carrying capacity of traditional and Langstroth hives results in overall average additional income to the extent of 16,220 and 17,379 SAR per beekeeper in the case of *Ziziphus* dominated valleys (Table 6), the income boosted by 121.69% and 130.39%, respectively, from the existing beekeeping practice. Similarly, following the optimum honeybee colony carrying capacity of the valleys in the case of *A. tortilis* valleys (Table 7), the overall additional income per beekeeper can be boosted up to 55,973 and 59,247 SAR for traditional and Langstroth hives, the income boosted by 196.49% and 207.98%, respectively, from the existing beekeeping practice. Workneh (2011) reported adopting improved box hive technology enhanced income by three folds what one would get from a traditional hive. In the present study, the major reason for an enhanced profit in both *Z. spina-christi and A. tortilis* honey flow seasons was due to the lower cost of production with a low number of colonies when the optimum carrying capacity of valleys is followed (Tables 6 and 7).

Acknowledgements

This work was funded by a grant from the National Plan for Science and Technology (NPST) at King Saud University (Project number 11-AGR1750-02), which is gratefully acknowledged.

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