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Impacts of *Prosopis juliflora* invasion on livelihoods of pastoral and agro-pastoral households of Dire Dawa Administration, Ethiopia

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Abstract

This paper examines impacts of *Prosopis juliflora* (hereinafter may be referred as '*Prosopis*') invasion on livelihoods of agro (pastoral) households using detailed household data in rural Dire Dawa Administration of Ethiopia. Cross-sectional data were collected from a total of 450 sample households whereby 250 were from *Prosopis*-invaded households and the remaining 200 from non-*Prosopis*-invaded households. The major research question of the study was, 'what would be the livelihoods of *Prosopis*-invaded households had they not been invaded by *Prosopis*?' To answer this question, descriptive and econometric tools were employed. The study results revealed that family size, dependency ratio and access to irrigation had negative and significant relationships with *Prosopis* invasion. On the other hand, age of the household head, Tropical Livestock Unit (TLU) and engagement in food for work programmes were positively related to *Prosopis* invasion. The results of this study show that the positive effects of *Prosopis* invasion were pronounced in terms of education expenditure, average annual income from crop production, off-farm income, food and non-food expenditure and physical food consumption, whereas there has been negative effects of *Prosopis* invasion due to reduced income generation from milk products. In this study, possible recommendations were drawn for stakeholders in order to reverse Prosopis adverse effects and optimize the positive impacts of this species in the study area.

Keywords: Pastoral, Agro-pastoral, *Prosopis juliflora*, Propensity score matching

Introduction

Ethiopia's natural resource base is the foundation of economic development, food security and other basic necessities of its people. Agriculture is the dominant sector of the country's economy that provides nearly 42% of GDP, 77% of employment, and 84% of exports (ATA 2015). In addition, majority of the agriculture sector consists of smallholder farmers who make their living from less than 2 ha of land. The sector is also a front-line victim of different environmental shocks including invasion of noxious plant species (FDRE, 2010). According to Stefan (2005), the impacts of invasive species on livelihoods are more pronounced in developing nations as the majority of their populations consist of small-scale farmers who are dependent on natural resources for their survival.

Invasive alien species out-compete native organisms for food and habitat, spread through their new environment, increase their population and harm ecosystems in their introduced range (Liba and Gretchen 2009). They cause ecological, economic and social impacts and are key drivers of global change. They inflict serious damage on ecosystem goods and services which are the lifeline of the human enterprise (Ross et al. 2014).

The Federal Government of Ethiopia has identified a number of major invasive plant species in the country and declared the need for their control and eradication (Taye et al. 2007). These include *Parthenium* (*Parthenium hysterophorus*), water hyacinth (*Eichhornia crassipes*), mesquite (*Prosopis juliflora*) and *Lantana camara* and *Acacia* species, such as *Acacia drepanolobium* and *Acacia*

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mellifera. The Environment Policy of Ethiopia, the Forest Resource Strategy and the National Biodiversity Strategy and Action Plan recognize invasive plant species to be growing threats to the biodiversity of the country and socio-economic welfare of the people (Anagae et al. 2004). At the regional level, however, there is a lack of clearly defined policy or strategy for the control and management of invasive species (Anagae et al. 2004; Dubale 2008) and little attempt has been made in terms of their research and management. This is the same for the Dire Dawa Administration.

Prosopis is one of the world's worst invasive alien species, causing severe environmental degradation to the arid and semi-arid lowlands of the Horn of Africa, andthreatening the livelihood and food security of pastoral and agro-pastoral communities (Tilahun et al. 2014). *Prosopis* has invaded most of the pastoral and agro-pastoral areas of Afar Regional State and Dire Dawa Administration. In Ethiopia, *Prosopis* has covered an area of one million hectares and more than 12,000 ha in Dire Dawa Administration (BoARD 2009). In the Middle Awash, about 30,000 ha of grassland, rangelands, water points and croplands are estimated to be occupied by *Prosopis* (Mehari 2008). *Prosopis* is now causing concern in Ethiopia. It has become a serious challenge to pastoralists and agro-pastoralists, the result of which it is considered as a burning issue for regional government and city administration, researchers, academia, development practitioners and policy-makers at various levels. Therefore, the primary objective of this paper is to analyse the impact of *Prosopis* invasion on livelihoods of pastoral and agro-pastoral households of the rural Dire Dawa Administration, Ethiopia. This research attempts to answer the following question: What would be the livelihood of *Prosopis*-invaded households had they not been invaded?

Study area

The study was conducted in the west of Dire Dawa city, and it covers a total area of 26,437 ha, which is nearly 20% of the area under the Administration. The study area has an estimated population of 17,800, nearly 16.5% of the rural population in the Administration. Agriculture (both crop and livestock production) is the mainstay of the economy in the study area. Subsistence mixed farming is practised by 93% of the farm households. Selling of firewood is the most common non-farm income-generating activity in the study area. Dire Dawa Administration is found in the eastern part of Ethiopia within the Awash Basin at about 515 km away from Addis Ababa and 333 km from the international port of Djibouti. The Administration is geographically located between 09° 25′ to 09° 50′ N latitude, and 41° 35′ to 42° 25′ E longitude (WWDSE 2003).

The climatic condition of Dire Dawa seems to be greatly influenced by its topography, which lies between 894 and 2,284 m above sea level and characterized by a warm and dry climate with a relatively low level of precipitation. The mean annual temperature of Dire Dawa is about 25.4 °C. The average maximum temperature of Dire Dawa is 31.4 °C, while its average minimum temperature is about 18.2 °C. The region has two rain seasons, that is, a small rain season from March to April and a big rain season that extends from August to September. The aggregate average annual rainfall that the region gets from these two seasons is about 604 mm. On the other hand, the region is believed to have an abundant underground water resource (IDP 2006).

Methods

Sampling and data collection methods

The study employed a multi-stage sampling procedure to collect primary data. Firstly, Dire Dawa Administration was chosen purposively since it is the second most *Prosopis*-infested area in Ethiopia next to the Afar National Regional States. In the second stage, among 38 rural *Kebele*[1] in the Administration, a census-type selection method was employed to select all the four *Prosopis*-invaded *Kebeles* and a purposive sampling method was used to select three non-invaded *Kebeles* based on their demographic, socio-economic and geographic similarity with the invaded *Kebeles*. Thirdly, 250 and 200 agro-pastoral households were selected from invaded *Kebeles* and non-invaded *Kebeles*, respectively, applying probability proportionate to size (PPS) technique to have a total of reasonable comparison with 450 agro-pastoral households. Data was collected using pre-tested survey questionnaire. The survey questionnaire constitutes different parts from which respondents were asked about their socio-demographic and economic profiles and characteristics. The survey was administered using experienced enumerators who could speak the local language. In addition, published and unpublished research reports from various governmental and non-governmental organizations were also reviewed.

Data analysis

The empirical data were analysed using descriptive, inferential and econometric tools. The descriptive statistics which were used for analysing data for this study include mean, standard deviation, percentages and tables. Besides, t test and chi-square test were used to test whether there is a statistically significant difference between the two groups (invaded and non-invaded households) in terms of continuous and categorical variables, respectively.

Impact estimation techniques

Impact estimation was conducted using an econometric model called propensity score matching (PSM) approach. We used the PSM developed by Rosembaum and Rubin (1983) to assess if invasion by *Prosopis* has a significant negative or positive effect on the livelihood of the invaded communities. PSM uses a statistical model to calculate propensity of invasion on the basis of the set of observable characteristics. Invaded and non-invaded households are then matched on the basis of similar propensity scores. The idea behind the PSM approach is to find control observations (that is, non-invaded households) having initial observable characteristics similar to the invaded households, to serve as valid surrogates for the missing counterfactuals.

This involves estimating a logit model that predicts the probability that each household is invaded as a function of observed household and community characteristics using a sample of invaded and non-invaded households. The model specification is checked to test equality of the means of these observed characteristics across the invaded (treatment sample) and non-invaded (control sample).

In estimating the logit model, the dependent variable is invasion by *Prosopis*, which takes the value of 1 if a household is invaded and 0 otherwise. The mathematical formulation of the logit model is as follows:

$$p_i = \frac{e^{z_i^i}}{1 + e^{z_{i_i}}} \quad (1)$$

where p_i is the probability that the '*i*th' households is invaded by *Prosopis*, Z_i is a linear function of *m* explanatory variables (X) and is expressed as

$$Z_i = a_o + a_1 x_{1i} + a_2 x_{2i} + a_3 x_{3i} + \cdots + a_m x_{mi} + U_i \quad (2)$$

where

$i = 1, 2, 3\ldots$ m

a_o = intercept

a_i = regression coefficients to be estimated

U_i = a disturbance term, and

X_i = pre-intervention characteristics.

The probability that a household belongs to the non-invaded group:

$$1 - p_i = \frac{1}{1 + e^{z_{i_i}}} \quad (3)$$

According to matching theory (Rosembaum and Rubin 1983; Bryson et al. 2002; Jalan and Ravallion 2003), the logit model via which the propensity score is generated should include predictor variables that influence the selection procedure and the outcome of interest. In this respect, the study was undertaken by including as many explanatory variables as possible to minimize the problem of unobservable characteristics in our evaluation of the impact of *Prosopis* invasion.

This approach assumes that after controlling for all pre-invasion observable household and community characteristics that are correlated with invasion and the outcome variables, non-invaded households have the same average outcome as invaded households would have had if they were not invaded. If not feasible to control for these characteristics, PSM estimation becomes biased. Having control households from the same communities as treatment helps to reduce the risks of such bias by providing a similar distribution of unobserved community characteristics.

It is also assumed that for each invaded household and for all observable characteristics, a comparison group of non-invaded household with similar propensity scores exists. Heckman et al. (1998) emphasize that the quality of the match can be improved by ensuring that matches are formed only where the distribution of the density of the propensity scores overlap between treatment and comparison observations or where the propensity score densities have 'common support'. Common support is improved by the dropping of all observations whose propensity scores are smaller than the minimum and larger than the maximum of the treatment and control, respectively (Caliendo and Kopeinig 2005).

The balancing property of the logit specification is tested to ensure that the sample of invaded households and the sample of non-invaded households have similar mean propensity scores and observables at various levels of propensity scores (Becker and Ichino 2002). Hence, the results are presented based on specifications that passed the balancing tests. Related to the balancing property of *p*-score is the conditional independence assumption (CIA), which states that the existence of *Prosopis* is random and uncorrelated with household income, once the set of observable characteristics, *X*, are controlled for. Sensitivity analysis was also undertaken to check if the influence of unobserved variables on the selection process is so strong as to undermine the matching procedure.

The general formula for the mean impact of *Prosopis* invasion on livelihoods of pastoral and agro-pastoral households is given by

$$\Delta C = \frac{1}{N_T} \sum_{i\epsilon\{D=1\}} \left[y_i,\ i - \sum_j w(i,\ j) y_0,\ j \right] \quad (4)$$

where $0 < w(i, j) \leq 1$, $\{D = 1\}$ is the set of treated individual, j is an element of the set of matched comparison units, N_T is the number in the treated group and i is the treated individual. Different matching estimators are generated by varying the choice of $w(i, j)$.

Variable definitions, measurement and working hypothesis

Variable definitions, measurement and working hypothesis of this study are found in Table 1.

Result

Descriptive results

As already noted, this study is based on data collected from a total of 450 sample households, of which 250 households belong to the four *Kebeles* invaded by *Prosopis* and the remaining 200 households belong to the three non-invaded rural *Kebeles* of the administration. As indicated in Table 2, the average age of respondents in *Prosopis*-invaded *Kebeles* was 42.49 years, whereas it is 38.58 years for the non-invaded *Kebeles*. Average family size of the households in *Prosopis*-invaded *Kebeles* was 6.302 persons or 5.578 in adult equivalent while that of the non-invaded households was 6.270 persons or 5.407 in adult equivalent. t test results for differences in age distribution was significant with a t value of −3.694, and family size between the two groups was insignificant ($t = -0.135$).

Proximity of households to market centre, the city and main road of Dire Dawa were also assessed, and the result showed that the average distances of the invaded and non-invaded households from the city were 3.824 and 13.736 km, respectively, while their corresponding distances from the main road were 1.840 and 2.475 km. t test results showed that there is a significant difference at 1% and 10% level of significance ($t = 20.614$ and $t = 1.918$), in

Table 1 Variable definitions and measurement

Variable	Type and definition		Measurement
Dependent variable			
TREATMENT	Dummy, invasion by *Prosopis*	1 for invaded households, 0 otherwise	
Outcome variables			
EDUEXPE	Continuous, education expenditure	Birr[a]	
FOaNFEXPE	Continuous, food and non-food expenditure	Birr	
HEALEXPE	Health expenditure	Birr	
CALINTAKE	Continuous, calorie per day per AE	Cal	
AAILS	Continuous, average annual income from livestock sale	Birr	
AAIMP	Continuous, average annual income from milk production	Birr	
AAICP	Continuous, average annual income from crop production	Birr	
AAFW/CP	Continuous, average annual income from fuel wood/ charcoal production	Birr	
OFFFARMIN	Continuous, average annual income from off-farm activities	Birr	
Explanatory variables			Hypothesis
AGEHH	Continuous, age of household head	Number of years	(+)
EDUHH	Dummy, education of household head	1 if illiterate, 0 otherwise	(+)
TOTHH	Continuous, family size	Number of household members	(−)
TOTALAND	Continuous, landholding size	Ha	(−)
IRRGTN	Dummy for access to irrigation	1 if has access to irrigation, 0 if not	(+/−)
SEXHH	Dummy for sex of household head	1 if male, 0 otherwise	(+)
DEPENRATIO	Continuous, dependency ratio	Ratio	(−)
TLU	Continuous, livestock-holding size	Tropical livestock units	(−)
CREDITACC	Dummy for access to rural credit service	1 if access to credit service, 0 if not	(+/−)
FARMEXPHH	Continuous	Number of years	(−)
SAFTYNT	Dummy for access to safety net programme	1 if a household head is engaged in safety net programme, 0 if not	(+)
DRTEF	Dummy for effect of drought	1 if a household's income from livestock and crop production decreases when compared to the normal year and 0 if it remains the same	(+/−)
DISROAD	Continuous, distance from main road	Km	(−)

Source: own definition
1USD = 19.25 Ethiopian Birr
[a]The unit of currency in Ethiopia

Table 2 Socio-economic characteristics of sample households by household type

Pre-interv. variables	Invaded *N* = (250)		Non-invaded *N* = (200)		Sample household *N* = (450)		Means difference		*t* value
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	
AGEHH	42.490	10.208	38.58	11.004	40.545	10.777	3.91	−0.796	−3.694***
Family size age between 15 and 64	3.411	1.802	2.970	1.756	3.192	1.791	0.441	0.047	−2.484**
DISROAD	1.840	2.421	2.475	4.027	2.155	3.330	−0.635	−1.606	1.918*
DISMKT	3.824	3.872	13.736	5.618	8.756	6.914	−9.912	−1.746	20.614***
FARMEXPHH	26.109	10.902	20.135	8.210	23.137	10.098	5.974	2.692	−6.202***
TOTHH	6.302	2.496	6.270	2.254	6.286	2.376	0.032	0.242	−0.135NS
DEPENRATIO	1.030	0.072	1.056	0.075	−0.026	−0.003	1.288	1.051	2.678***
HH size in AE	5.578	2.152	5.407	1.894	5.493	2.027	0.171	0.258	−0.843NS
TOTALAND	2.621	2.369	2.148	2.211	5.493	2.027	0.474	0.158	−2.073**
TLU	5.033	3.214	4.610	3.271	4.820	3.246	0.423	0.057	1.308NS

Source: own survey data, 2015
*, ** and *** mean significant at the 10%, 5% and 1% probability levels, respectively
Not significant (NS)

proximity of households to market centre and main road, between the two groups, respectively (Table 2).

A closer look at economically active family members in the sampled households (15 to 65 years old) showed that the treatment group of households (invaded households) had relatively larger active family members, accounting to about 3.411 persons, than the control group of households which was found to be about 2.790 persons. This implies that, on average, the households from the invaded *Kebeles* have relatively more labour force than those households from the non-invaded *Kebeles*. However, the treatment group of households showed a slightly lower average dependency ratio (1.030) than households from the control group (1.056). This implies that every economically active person in the *Prosopis* invaded households and non-invaded households had to support more than one economically inactive person.

Farm experience of the sampled households was also assessed, and the result showed that, on average, *Prosopis*-invaded households had 26.109 years of farm experience while non-invaded had an average of 20.135 years farm experience. *t* test results, as showed in Table 2, indicated that there is a significant difference in farm experience of household heads at 1% level of significance ($t = -6.202$) between the two groups.

Livestock holding, as a wealth variable, indicates the capacity of agro-pastoral household to involve in high-return income sources. As shown in the table below, livestock holding in TLU was 5.033 for the treatment group and 4.610 for the control group. This implies that livestock per capita in the invaded areas was higher than that in the non-invaded areas, even if the *t* test result presented in Table 3 shows the difference is insignificant ($t = 1.308$).

As is the case in the majority of farm households in the country, land is one of the scarce factors of production in the study area. Land holdings of sampled households varied from no farm land (1.7%) to greater than 1 ha (30.2%) out of which 20.2% belonged to the treatment (invaded) areas and the remaining 10% belonged to the control (non-invaded) group. This implies that the largest share (49.1%) of the households in the study area own less than one hectare of farm land.

Survey results also showed that 3.1% from the control (non-invaded) group and 2.4% from the treatment group held less than 0.5 ha of farmland. About 10.9% from the control and 11.1% from the treatment group owned 0.5 ha of farmland, while 10.2% of households in the control group and 10.4% of households in the treatment (invaded) group owned 1 ha of farmland. The small size of plots or farmlands accompanied with some environmental stresses in the study areas further aggravated the already existing agricultural practice and of course adversely affected crop production.

As far as educational status of the respondents is concerned, nearly 80% and 66% of households from *Prosopis*-invaded and non-invaded *Kebeles* were illiterate, respectively. Only 19.80% from the invaded and 34% from the non-invaded *Kebeles* attended primary education. The

Table 3 Farm holding size of sample households by household type

Land size (ha)	Non-invaded		Invaded		Total	
	Number	%	Number	%	Number	%
No farm land	2	0.4	6	1.3	8	1.7
<0.5	14	3.1	11	2.4	25	5.6
=0.5	49	10.9	50	11.1	99	22
$0.5 < x < 1$	44	9.8	45	10.0	89	19.8
=1	46	10.2	47	10.4	93	20.7
>1	45	10.0	91	20.2	136	30.2
Total	200	44.4	250	55.6	450	100.0

Source: own survey data, 2015

result of chi-square test showed that there was a significant difference in the educational status of household heads at 1% level of significance between the two groups (χ^2 = 10.311). As the result indicates, majority of households who are invaded by *Prosopis* were illiterates.

Survey results showed that, out of the total 450 sampled households, 85% and 15% were male headed and female headed, respectively (Table 4). The results also indicated that 88% and 12% of *Prosopis*-invaded households and 82% and 18% of non-invaded households were male headed and female headed, respectively. *t* test result for differences in gender of the household head between the two groups was significant ($t = -2.963$)

In both *Prosopis*-invaded and non-invaded areas, it was observed that 64.4% and 50.5% of the respondents were engaged in food for work or the so-called safety net programme, respectively. This implies that more than half of the households are not in a position to feed themselves from income generated from crop and livestock production. Besides, the average number of food secured and food insecure households was assessed based on the calorie intake levels of sample respondents, and the results revealed that 59.5% of the respondents in non-invaded areas and 49.6% of the respondents in the invaded areas were food insecure. This means that in both cases, there is almost food uncertainty. The result of the chi-square test showed that there is a significant difference among the two groups in number of food secured people at 5% level of significance ($\chi^2 = 4.048$) (Table 4).

In the study area, both perennial and annual crops are grown through rain-fed and irrigation agriculture. Subsistence mixed farming is the dominant farming type constituting 81.25% of the households in the study area. Irrigation accounts for about 27.72% of the households in the control (non-invaded) areas and only 8.8% in the treatment (invaded) areas. The chi-square test was also undertaken to check whether there is a significant mean difference in households' access to irrigation between the two groups. The result showed that the difference was significant at 5% ($\chi^2 = 6.544$) (Table 4).

In the study area, it was observed that 41.2% of the respondents in the invaded areas and 33.66% of the respondents in the non-invaded areas have access to rural credit service. As can be seen from Table 4, the chi-square test result indicated that there is insignificant difference in access to rural credit service between the two groups.

As far as cooperative membership is concerned, nearly 71.6% from *Prosopis*-invaded *Kebeles* and 46.50% from the non-invaded *Kebeles* are not members of cooperative respectively. The result of chi-square test showed that there was a significant difference in household heads' membership to a cooperative, at 1% level of significance between the two groups ($\chi^2 = 25.604$).

Table 5 shows that there were significant differences between the two groups of sample respondents with

Table 4 Socio-economic characteristics of sample households by household type

Pre-interv. variables	Description	Invaded		Non-invaded		Total		χ^2 value
		(N = 250)		(N = 200)		(N = 450)		
		No.	%	No.	%	No.	%	
SEXHH	MALE	220	88	164	82	384	85	2.963*
	FEMALE	30	12	36	18	66	15	
EDUHH	Illiterate	200	80	132	66	332	73	10.311***
	Literate	50	20	68	34	118	27	
	Yes	71	28.4	145	72.50	216	50.45	25.604***
	No	179	71.6	94	46.50	273	59.05	
CREDITACC	Yes	103	41.2	68	33.66	171	37.43	2.153NS
	No	147	58.8	132	65.35	279	62.08	
DRTEF	Yes	175	70	190	94.06	365	82.03	43.879***
	No	75	30	10	4.95	85	17.475	
Number of food secured people	Food secure	126	50.4	81	40.5	207	45.45	4.048**
	Not food secure	124	49.6	119	59.5	243	54.55	
SAFTYNT	Yes	161	64.4	102	50.5	263	57.45	7.346***
	No	89	35.6	98	48.51	187	42.06	
IRRGTN	Yes	22	8.8	56	27.72	78	18.26	24.383***
	No	228	91.2	144	71.29	372	81.25	

Source: own survey data, 2015

*, ** and *** mean significant at the 10%, 5% and 1% probability levels, respectively

Not significant (NS)

Table 5 Current income, expenditure and calorie intake of sample households by household type

Pre-interv. variables	Invaded *N* = (250)		Non-invaded *N* = (200)		Sample household *N* = (450)		Means difference		*t* value
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	
EDUEXPE	562.644	485.170	366.620	301.501	465.119	415.608	169.024	183.669	−4.860***
AAILS	1,719.946	2,651.149	2,161.128	2,267.842	1,939.439	2,474.703	−441.182	383.307	1.792*
AAIMP	656.990	1,130.953	941.050	1,663.434	798.313	1,426.359	−284.06	−532.481	2.004**
AAFW/CP	1,235.460	2,223.456	561.200	1,529.271	900.008	1,937.154	674.26	694.185	−3.539***
AAICP	3,053.03	2,350.367	2,215.006	1,881.04	2,636.106	2,168.163	838.031	469.326	−3.944***
OFFFARMIN	6,173.871	9,412.567	5,036.040	14,727.954	1,137.831	−5,315.39	5,607.786	12,344.151	−0.9240NS
FOaNFEXPE	9,879.327	5,684.264	6,429.45	5,636.152	8,162.970	5,911.239	3,449.877	48.112	−6.110***
HEALEXPE	243.158	252.378	153.170	295.857	198.388	278.198	89.988	−43.48	−3.282***
CALINTAKE	2,704.443	1,718.556	1,859.700	1,165.135	2,284.173	1,527.393	844.743	553.422	−5.763***

Source: own survey data, 2015
*, ** and *** mean significant at the 10%, 5% and 1% probability levels, respectively
Not significant (NS)

respect to expenditure on education, milk income, income from livestock sale, income from *Prosopis*, average annual income from crop production, food and non-food expenditure, health expenditure and calorie per day per Adult-Equivalent (AE). However, there were no statistical significant differences between the two groups of sample households with respect to off-farm income. The explanation for the significant outcome variables are presented below.

Expenditure on education includes money spent on exercise books, pens, pencils, uniform, school fees and other education materials of the previous year. The mean education expenditure of the total sample households is Birr 465.119 (USD 24.162) per annum. The average education expenditure for *Prosopis*-invaded and non-invaded households is Birr 562.644 (USD 29.228) and Birr 366.620 (USD 19.045), respectively. The *t* test result shows that there is statistically significant difference among the two groups at 1% probability level.

The quantity of milk from the households who own livestock was estimated on the basis of the number of milking animals and the amount of milk that the average cows, goats, sheep and camels produced. Explicit costs including annual average cost for medication and supplementary feed cost were also considered with the assumption that income from milk production is equal to domestic consumption plus sale. The descriptive result shows that there is significant difference between the two groups of households in that the mean income from milk production by *Prosopis*-invaded and non-invaded households is Birr 656.990 (USD 34.129) and Birr 941.050 (USD 48.886), respectively. The *t* test result reveals that there is statistically significant difference between the two groups at 5% probability level. According to the respondents, reduced pasture availability (caused by mesquite invasion) and frequent rain shortage caused the problem. Pasture availability is of course one of the factors determining milk productivity. A comparative study conducted by Mugasi et al. (2000) showed that livestock reared under relatively highly encroached grazing fields yielded less milk than those reared under less encroached fields.

Income from livestock sale is the sum of money households obtained from sale of live livestock. The mean income from livestock sales in *Prosopis*-invaded and non-invaded households is Birr 1719.946 (USD 89.348) and Birr 2161.128 (USD 112.266), respectively. The *t* test result reveals that there is statistically significant difference between the two groups at 10% probability level. This study is in line with Pasiecznik (1999) which reported that mesquite invasion forms impermeable, dense thickets. The same source also stated that the invasion reduces grass cover of grazing lands and consequently affects stocking density.

Income from fuel wood and charcoal is a sum of money households obtained from fuel wood collection and charcoal making. The mean income from fuel wood and charcoal in *Prosopis*-invaded and non-invaded households is Birr 1235.460 (USD 64.180) and Birr 561.200 (USD 29.153), respectively. The *t* test reveals that there is statistically significant difference in income generation from firewood collection and charcoal making.

Explicit costs such as costs for fertilizer, pesticides, seeds and labour, taking a minimum wage of Birr 20 per day, was used in the calculation of net income from crop production. These quantities were converted to values (Birr) using households' self-report of sales price. Based on this estimation, the mean annual income generated from crop production in *Prosopis*-invaded households is Birr 3053.03 (USD 158.599) while it is Birr 2215.006 (USD 115.065) for non-invaded households. There is a significant difference in income generated from crop production between invaded and non-invaded households, and the *t* value of −3.944 suggests that this variable is significant at 1% probability level. This study is also in line with Haji and Mohammed (2013) who confirmed that

Prosopis is attributed to have resulted in increased crop yields by 29%. *Prosopis* have positive effects on the soil layer (Ilukor et al. 2014). These positive soil characteristics can be used for consecutive planting of native species on cropping fields. In some studies, the physico-chemical property of soil under mesquite canopy was found to be better than the adjacent open field (e.g. El Fadl, 1997, cited in Esther and Brent 2005) which may be due to nitrogen fixation, leaf litter addition and change in soil structure due to deep tap root system (Pasiecznik et al. 2001).

An effort has also been made to study the expenditure pattern among the households which is presented below.

Total household expenditure includes food and non-food expenditure of households in the previous year. The mean total household expenditure of invaded and non-invaded households is Birr 9879.327 (USD 513.212) and Birr 6429.45 (USD 333.997), respectively. The *t* test result reveals that there is a statistically significant difference between the two groups at 1% probability level.

Health expenditure is a sum of money spent for medication by the household for family members and their animals. The mean health expenditure of *Prosopis*-invaded and non-invaded households is Birr 243.158 (USD 12.6316) and Birr 153.170 (USD 7.957), respectively. The *t* test result reveals that there is statistically significant difference between the two groups at 1% probability level.

Findings of the study show that invaded households and non-invaded households had calorie intake of 2704.443 and 1859.7 cal per AE, respectively. As already mentioned, two weeks' data on available food for sample households' consumption, from purchase and/or stock, were converted to kilocalories and the figures were divided by the total AE in each households AE. Finally the computed kilocalorie per AE in each household was compared with the minimum subsistence energy requirement per AE per day, 2,100 kcal. Invaded households' calorie intake is higher than non-invaded households (see Table 5).

Although education expenditure, income from fuel wood collection and charcoal making, income from crop production, food and non-food expenditure, health expenditure and calorie per day per AE of the invaded households were higher than those of non-invaded households, milk income and income from livestock sale in the invaded households were less than those of non-invaded households. However, this does not mean that the mean difference is exclusively because of the invasion of *Prosopis*. Since comparisons are not yet restricted to households who have similar characteristics, it is impossible to attribute the difference in the above variables between the two groups exclusively to *Prosopis* invasion. Therefore, to handle this shortcoming, a further analysis was conducted using propensity score matching techniques to strengthen the findings.

Estimation results

This section describes the steps followed to measure the impact of *Prosopis* invasion. More precisely, it presents the estimation of propensity scores, matching methods, common support region and balancing test. It also explains the treatment effect of *Prosopis* invasion across the invaded households.

Propensity scores

The results of a propensity score are obtained as the probability scores of individuals from the fitted simple logistic regression model. Logistic regression is applied when the dependent variable is dichotomous. The model is estimated with STATA 13 computing software using the propensity score matching algorithm developed by Leuven and Sianesi (2003). In the estimation process, data collected from the two groups, namely *Prosopis*-invaded households and non-invaded households, were pooled such that the dependent variable takes a value 1 if the household was invaded by *Prosopis* and 0 otherwise. Prior to running the regression model, the explanatory variables were checked for the existence of multi-collinearity and heteroscedasticity.

The Variance Inflation Factor (VIF) values of the variables in the model, as shown in Tables 12 and 13 in the Appendix, are less than the critical values showing that there is no problem of collinearity.

Heteroscedasticity was checked, and no problem was noticed in the data. As mentioned earlier, the variables included in the model are assumed to affect neither a household's invasion with *Prosopis* nor the outcome of *Prosopis* invasion.

The overall model goodness of fit represented by model count R^2 is very good, and about 88% of the variation in outcome is explained by the explanatory variables in the model. The log likelihood ratio which follows the chi-square distribution was found to be 224.935 which is significant at 1% probability level, which implies that the entire explanatory variables together explained the variation in the dependent variable.

As can be seen from the estimated coefficients of all the 14 explanatory variables, *Prosopis* invasion is significantly influenced by six of them. More precisely, family size, dependency ratio and access to irrigation water had shown negative and significant relationship with *Prosopis* invasion. On the other hand, age of the household head, TLU and engagement in food for work programme were positively and significantly related to *Prosopis* invasion.

Dependency ratio of the respondent household was found to significantly and negatively affect *Prosopis* invasion, which is also in line with the hypothesis. This means that higher dependency ratio leads to lesser probability of the households to be invaded by *Prosopis*.

Households, who have large family size, have a significant and at the same time negative relationship with *Prosopis* invasion. This means that larger family size contributes large family labour to use *Prosopis* as source of income or more labour is available in the house for fuel wood collection. Therefore, households who have larger family sizes have a lower probability to be invaded by *Prosopis*.

In line with the hypothesis, age of the household head was found to be positively related with *Prosopis* invasion. This means that as the age of household head increases, his/her potential ability to eradicate *Prosopis* decreases due to limited working capacity.

Households who participated in food for work (safety net) programme were found to have a significant and positive relationship with *Prosopis* invasion, which is also in line with the hypothesis. This means households benefiting from this programme favour *Prosopis* as they will not use it as a source of income.

Livestock holding as a wealth variable indicates the capacity of the agro-pastoral household to involve in high-return income sources. The result, as shown in the table below, for livestock holding is not in line with the hypothesis. It is interesting that for the households who owned larger number of livestock, the higher the probability to be invaded by *Prosopis.* This is because, when agricultural/farm land of the households are invaded by *Prosopis*, they will find other income source for their living. Particularly agro-pastoral households want to expand livestock production as the result of invasion. The model output is depicted in Table 6.

Figure 1 shows the distribution of households with respect to estimated propensity scores. As can be seen in the figure, most of the treatment households are found to the right of the distribution, while most of the control households are found in the left side of the distribution.

Table 6 Results of the logistic regression model

Variables	Coef.	Std. err.	z	$P > z$
AGEHH	0.0715	0.0206	3.48***	0.001
SEXHH	0.3138	0.5473	0.57	0.566
EDUHH	−0.1205	0.4881	−0.25	0.805
DISROAD	0.0448	0.0588	0.76	0.446
FARMEXPHH	−0.0129	0.0246	−0.52	0.601
TOTHH	−0.2301	0.0905	−2.54**	0.011
DEPENRATIO	−0.4194	0.04724	−8.88***	0.000
TOTALAND	−0.2254	0.0794	−1.25	0.245
TLU	0.2149	0.0614	3.50***	0.000
IRRGTN	−1.8196	0.5134	−3.54***	0.000
CREDITACC	0.5186	0.4623	1.12	0.262
SAFTYNT	1.5612	0.4841	3.22***	0.001
DRTEF	−0.9156	0.5816	−1.57	0.115
_cons	0.6698	1.1556	0.58	0.562
Number of obs = 450				
LR $\chi^2(13)$ 352.80				
Prob > χ^2 = 0.0000				
Log likelihood = −102.24075				
Pseudo-R^2 = 0.6331				

Source: own estimation result
*, ** and *** mean significant at the 10%, 5% and 1% probability levels, respectively

Matching of *Prosopis*-invaded households and non-invaded households

As noted earlier, before implementing the matching task, three main steps must be followed and these are presented as follows: First, predicted values of propensity scores should be estimated for all treated and control households. Second, a common support condition should be imposed on the propensity score distributions of household with and without the *Prosopis* invasion. Finally, observations whose predicted propensity scores fall outside the range of the common support region should be discarded.

The estimated propensity scores vary between 0.0496 and 0.996 (mean = 0.643) for *Prosopis*-invaded or treatment households and between 0.0163 and 0.965 (mean = 0.361) for non-invaded (control) households (Figures 2 and 3). The common support region would then lie between 0.0496 and 0.965. This means households whose estimated propensity scores are less than 0.0496 or greater than 0.965 were not considered for the matching exercise. As a result of this restriction, 10 households from treatment were discarded from the analysis (see Table 7).

Choice of matching algorithm

In order to get the best matching estimators for matching the treatment and control households in the common support region, the nearest neighbour, caliper and kernel matching estimators were tested (Table 8). Finally, the matching estimators make use of different criteria such as equal means test referred to as the balancing test (Dehejia and Wahba 2002), pseudo-R^2 and matched sample size. In selecting a given matching estimator, a matching estimator which balances all explanatory variables (i.e. results in non-significant mean differences between the two groups) bears a low R^2 value and also results in a large matched sample size which is preferable. Consequently, a kernel matching with no bandwidth was found to be the best estimator for the data.

Table 9 depicts the estimated results of matching quality tests. Based on the selected best estimator (kernel matching with no bandwidth), the balancing test of covariates, before and after the matching of *Prosopis*-invaded and non-invaded households, shows that there are no statistically significant mean differences

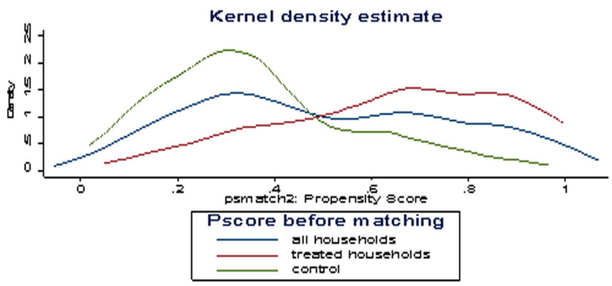

Figure 1 Distribution of households with estimated propensity scores

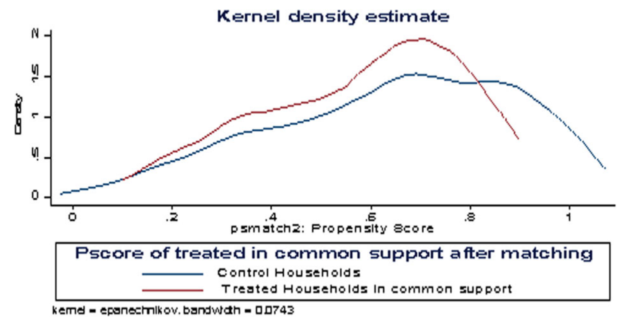

Figure 3 Kernel density of propensity scores of invaded households

between the two groups in terms of age of the household head, distance to the main road, sex of the household head, education level of the household head, farm experience, family size of the household, dependency ratio, farm size, access to irrigation, participation in safety net programme and drought faced during the last three years.

Treatment effect on the treated

The effect of *Prosopis* invasion on households' livelihoods was meticulously analysed. The estimated results show supportive evidence of statistically significant impact of *Prosopis* invasion on household expenditure on education, milk income, average annual income from crop production, off-farm income, food and non-food expenditure and food poverty measured in calorie intake. Pre-intervention differences (demographic, location, institutional and asset endowment characteristics) among the *Prosopis*-invaded and *Prosopis* non-invaded households were controlled.

The finding of this study revealed that mean difference in education expenditure, milk income, calorie intake per AE and average annual income obtained from fuel wood collection and charcoal making between the two groups of sample households is significant at 1% probability level. For food and non-food expenditure, the two groups of sample households showed significant mean difference at 5% probability level. Results also show that average annual income from milk, average annual incomes from crop production and off-farm income are significant at 5% probability levels. In other words, on average, *Prosopis* invasion has boosted education expenditure, average annual income from crop production, off-farm income, food and non-food expenditure, physical food consumption and income from fuel wood and charcoal in *Prosopis*-invaded household by Birr 213.053 (USD 11.068), Birr 529.43 (USD 27.503), Birr 3831.295 (USD 199.028), Birr 2607.103 (USD 135.434), 805.421 cal and Birr 2133.399 (USD 110.826), respectively, over the non-invaded households. On the other hand, *Prosopis* invasion has reduced milk income by Birr 410.667 over the non-invaded households (Table 10).

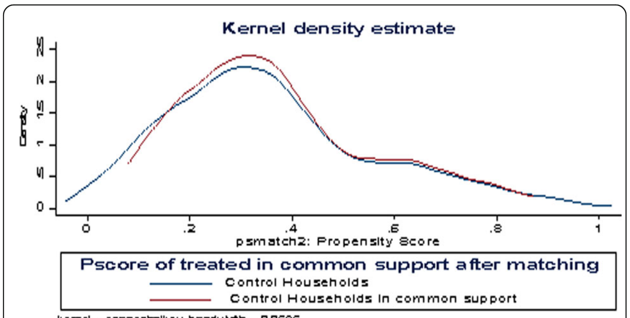

Figure 2 Kernel density of propensity scores of non-invaded households

Sensitivity analysis

In this section, the issue whether or not the final evaluation results are sensitive with respect to the choice of the balancing scores is addressed. Matching estimators work under the assumption that a convincing source of exogenous variation of treatment assignment does not exist. Likewise, sensitivity analysis was undertaken to detect if the identification of conditional independence assumption was satisfactory or affected by the dummy confounder or the estimated Average Treatment Effect on the Treated (ATT) is robust to specific failure of the CIA. Sensitivity analysis using the bounding approach was employed, and this involves calculating upper and lower bounds, using the Wilcoxon signed rank test. These rank tests test the null hypothesis of no-treatment effect for different hypothesized values of unobserved selection bias. Table 11

Table 7 Distribution of sample households by estimated propensity scores and household type

Group	Obs	Mean	Std.	Minimum	Maximum
Total households	450	0.502	0.263	0.0163	0.996
Treatment households	250	0.643	0.239	0.0496	0.996
Control households	200	0.361	0.204	0.0163	0.965

Source: own estimation result

Table 8 Comparison of the three matching estimates by performance criteria

Matching estimator	Performance criteria		
	Balancing test[a]	Pseudo-R^2	Matched sample size
NN			
1 neighbour	8	0.109	440
2 neighbour	8	0.082	440
3 neighbour	9	0.067	440
4 neighbour	10	0.064	440
Caliper			
0.01	12	0.038	396
0.25	12	0.055	440
0.5	7	0.134	440
KM			
With no bandwidth	13	0.033	440
Bandwidth of 0.1	11	0.042	440
Bandwidth of 0.25	11	0.050	440
Bandwidth of 0.5	8	0.084	440

Source: own estimation result

[a]Number of explanatory variables with no statistically significant mean differences between the matched groups of *Prosopis*-invaded households and non-invaded households

reveals the sensitivity result of outcome ATT values to the dummy confounder.

Regarding milk income, off-farm income, income from crop production and income from *Prosopis*, the average treatment effect on the treated is found to be insensitive to the dummy confounder. Similarly, education expenditure, food and non-food expenditure and calorie per day per AE were also found to be robust or insensitive to the dummy confounder. This shows how strongly an unmeasured variable influences the selection process in order to undermine the implications of matching analysis.

Conclusions

In this study, cross-sectional data from *Prosopis*-invaded and non-invaded *Kebeles* of rural Dire Dawa Administration were used to explore the impacts of *Prosopis* invasion on households' welfare. The main question that this research attempted to answer was, 'what would be the livelihoods of *Prosopis*-invaded households had they not been invaded by Prosopis?' Answering this question requires observing outcomes with and without the *Prosopis* invasion for the same household. However, it is impossible to observe the same object in two states simultaneously. In other words, the fundamental problem in any social programme evaluation is the missing data problem. While the programme evaluator observes the factual for an object, it is impossible to observe the counter-factual for the same object.

This study used the propensity score matching technique to eliminate the possible sample selection bias since the data were from a survey study. *Kebeles* were grouped into two strata. Stratum one, which represent the treatment group, consists of four *Kebeles* that are severely invaded by *Prosopis*. The other three *Kebeles* which are not invaded by *Prosopis* are categorized under stratum two representing the control group.

The present study is a comparison between *Prosopis*-invaded *Kebeles* forming four in number and *Prosopis* non-invaded *Kebeles* numbering three. As expected, a household's invasion by *Prosopis* was determined by a

Table 9 Results of the balancing tests of covariates using the kernel matching estimator

Variables	Before matching (450)			After matching (440)		
	Treated	Control	*t* value	Treated	Control	*t* value
	N = (250)	*N* = (200)		*N* = (240)	*N* = (200)	
AGEHH	42.490	38.580	3.690***	42.032	43.368	−1.220
SEXHH	0.881	0 .820	1.720*	0.871	0.890	−0.570
EDUHH	0.198	0.340	−3.240***	0.204	0.321	−0.120
DISROAD	1.840	2.475	−1.920*	1.806	1.552	0.770
FARMEXPHH	26.109	20.135	6.200***	25.317	26.357	−0.990
TOTHH	6.302	6.270	2.560**	6.274	6.856	−0.130
DEPENRATIO	1.149	1.428	−2.680***	1.146	1.261	−1.160
TOTALAND	2.621	2.1475	2.070**	2.534	3.0487	−1.560
TLU	5.033	4.610	2.310**	4.788	4.661	0.400
IRRGTN	0.089	0.280	−5.080***	0.0914	0.114	−0.720
CREDITACC	0.411	0.340	1.470	0.362	0.325	0.680
SAFTYNT	0.644	0.510	2.730***	0.577	0.535	0.740
DRTEF	0.698	0.950	−7.000***	0.731	0.653	1.640

Source: own estimation result

*, ** and *** means significant at 1%, 5% and 10% probability levels, respectively

Table 10 Average treatment effect on the treated (ATT)

Variables	Treated	Controls	Difference	*t* value
EDUEXPE	572.646	359.593	213.053	3.63***
FOaNFEXPE	9,894.328	7,287.226	2,607.103	2.95**
HEALEXPE	260.349	215.813	44.536	0.48NS
CALINTAKE	2,673.691	1,868.270	805.421	3.96***
AAILS	1,676.303	1,796.247	−119.945	−0.33NS
AAIMP	677.241	1,087.908	−410.667	−1.68*
AAICrP	4,436.468	3,907.037	529.430	1.70*
OFFFARMIN	6,030.369	2,199.075	3,831.295	1.78*
AAFW/CP	2,257.849	124.450	2,133.399	4.57***

Source: own estimation result
*, ** and *** means significant at 1%, 5% and 10% probability levels, respectively
Not significant (NS)

combination of factors. These are age of the household head, family size of the household, dependency ratio, access to irrigation water, TLU and engagement in food for work programme. Finding a reliable estimate of the *Prosopis* impact thus necessitates controlling for all such factors adequately. In doing so, propensity score matching has resulted in 240 treated households to be matched with 200 controlled households. In other words, a matched comparison of all outcome variables was performed on these households who shared similar pre-intervention characteristics except the *Prosopis*. The resulting matches passed a variety of matching quality tests and were fit for addressing the main objectives of this study.

After controlling for other characteristics, it has been found that *Prosopis* invasion had significantly boosted the *Prosopis*-invaded household, over the non-invaded households on education expenditure by Birr 213.053 (37.23%), average annual income from crop production by Birr 529.43 (11.93%), off-farm income by Birr 3831.295 (63.53%), food and non-food expenditure by Birr 2607.103 (26.35%) and physical food consumption by 805.421 cal per AE (30.12%). On the other hand, *Prosopis* invasion reduces milk income of the *Prosopis*-invaded household by Birr 410.667 (60.64%) over the non-invaded households. Although this study tried to capture some aspects of the *Prosopis* invasion in the rural Dire Dawa Administration, more aspects of *Prosopis* invasion such as more benefits and social costs were not examined, making the total economic evaluation incomplete.

Table 11 Sensitivity analysis of the estimated ATT

Outcome variables	Percentage change
EDUEXPE	4.63
AAIMP	13.74
AAICrP	4.68
OFFFARMIN	12.47
FOaNFEXPE	8.23
AAFW/CP	2.19
CALINTAKE	5.45

Source: own estimation result

Recommendations

Based on our results, we provide the following recommendations for the sustainable management and control of *Prosopis* in the Dire Dawa Administration.

First, any projects or programmes that aim to tackle the challenges of *Prosopis* invasion and optimize the positive impacts of this species need to consider the *Prosopis* invasion effects explicitly, as there is huge market failure and externalities relative to the *Prosopis* invasion. Moreover, active involvement of the local community is important in the design and success of *Prosopis* invasion control/eradication programmes. So raising awareness of the local community about the pros and cons of *Prosopis* effects on households' welfare will play a great role for the success of community-based *Prosopis* invasion control/eradication programmes. Hence, before trying to mobilize the community in control/eradication of *Prosopis* invasion, an awareness creation activity has to be done.

Second, age of the household head was found to be positively related to the probability of *Prosopis* invasion. Therefore, encouragement must be given to older household heads on the control/eradication of *Prosopis* invasion. In other words, development agencies and policy-makers should target *Prosopis* control/eradication technologies on the basis of age.

Third, households with large family size found to have lesser probability to be invaded by *Prosopis* because the family could have contributed higher labour force invasion can be an opportunity. Projects/programmes that work on efficient family labour allocation and family planning need to be encouraged in maintaining and minimizing household size to the level of household income capability. The implementation of family planning programmes should be supported with the current health-extension package of giving high emphasis on local people's perception of household size and on their attitudes towards family planning facilities.

Fourth, livestock rearing is the most important economic activity for the agro-pastoral households in the study area. Projects like dairy cow credits, sheep and goat credits, camel credit and fattening need to be supported through establishment of organized credit facilities, together husbandry skill and knowledge training for improvement of livestock management to increase family income can gain capacity to control/eradicate *Prosopis* invasion. Management of herds (stocking and restocking) and utilization of improved feed and fodders in combination with *Prosopis* as a feed source need to be given due attention. Side by side, the extension service needs to give due attention to problems of animal health and critical feed shortage. In addition, necessary inputs should be provided on time, as per the requirement of the farmers.

Fifth, food security programmes are positively related to *Prosopis* invasion. Therefore, government and NGO intervention with regard to food aid and different food security programmes and projects have to take into consideration the negative impacts of *Prosopis* invasion. Since some invaded households gain a good source of income, promoting Prosopis utilization in a planned way through adoption of appropriate and sustainable management is advisable in the study area.

Sixth, the study results also indicated that access to irrigation was negatively related to *Prosopis* invasion. Therefore, in order to address the *Prosopis* invasion problems in the study area, attention should given by GOs and NGOs to developing small-scale irrigation or water harvesting technology, by organizing farmers into watershed cooperatives.

Seventh, due to the fact that the local communities in the invaded area have a record of better harvest in lands cleared of *Prosopis*, converting some of the invaded grazing lands into cultivable land (especially sorghum) is also another point of recommendation.

Last, but not the least, further research is needed on the total economic valuation of *Prosopis* invasion on the administration so as to gain more insight into the impact of *Prosopis* invasion.

Endnote

[1]A *Kebele* is the smallest administrative unit of Ethiopia similar to a ward.

Appendix

Table 12 Multi-collinearity test for all explanatory variables

	Collinearity statistics	
	Tolerance	VIF
AGEHH	.537	1.862
SEXHH	.894	1.118
EDUHH	.769	1.301
DISROAD	.771	1.297
FARMEXPHH	.449	2.227
TOTHH	.736	1.358
DEPENRATIO	.825	1.213
TOTALAND	.775	1.290
TLU	.720	1.388
IRRGTN	.632	1.583
CREDITACC	.706	1.417
SAFTYNT	.696	1.436
DRTEF	.736	1.359

Table 13 Contingency coefficient among discrete explanatory variables

	EDUHH	IRRGTN	CREDITACC	SAFTYNT	DRTEF	OFFFARM
EDUHH	1	0.173	0.041	0.182	0.045	0.019
IRRGTN		1	0.235	0.145	0.183	0.120
CREDITACC			1	0.375	0.112	0.012
SAFTYNT				1	0.157	0.174
DRTEF					1	0.058
OFFFARM						1

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Authors' contributions

All authors of this manuscript have directly participated in the planning and execution of this study, and therefore, we confirm that the manuscript has been read and approved by all named authors.

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Competing interests

The authors declare that they have no competing interests.

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