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Goal programming and analytical hierarchy process approaches for sustainable plantation

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ABSTRACT
The aim of this study was to develop an optimal sustainable forest plantation based on goal programming and Analytic Hierarchy Process (AHP) methods. This study was carried out in Guilan province, north of Iran. First of all, the ecological capability of the study area for plantation establishment/maintenance was evaluated based on multi-factor method and specific ecological Makhdoum Model by means of GIS tools. Then goal programming approach as a multi criteria optimization technique was used for optimization. Therefore, ecological, economic and social aims were considered. Carbon sequestration was chosen as an ecological criterion. To estimate the total aboveground biomass and carbon content stem volume, stem biomass and crown biomass were measured using allometric equations. The net present value was also calculated using stumpage price, harvesting cost, consumer price index, annual growth, interest rate and optimal rotating. Estimated required labour for different plantation items were obtained from data base of Iranian Forests Rangelands and Watershed Management Organization. In order to achieve all purposes simultaneously, the goal programming technique was applied. Results indicated that using mathematical modeling provided a more logical set of consequences compared to using ecological modeling. The ability to change the weighting of the variables in the mathematical equations enabled decision makers to choose the optimal solution. Final results indicated that the appropriate plantation area for each species are as follow: *Acer velutinum* (810 ha), *Alnus subcordata* (348 ha), *Pinus taeda* (235 ha), *Tilia begonifolia* (165 ha), *Quercus castanifolia* (149 ha), *Pinus nigra* (110 ha) and *Fraxinus excelsior* (0 ha).

Keywords: *Allometric equations, Analytical hierarchy process, Ecological capability evaluation, Goal programming*

INTRODUCTION
The Rio Declaration (UNCED, 1992), United Nations Forums on Forests (UNFF), and other international processes, meetings and key publications, have recognized the critical role of forestry in the future sustainability of the world's resources. The role of planted forests, in achieving sustainable development and mitigating the effects of climate change is critical. The significance of planted forests (plantations) and recognition of their contributions to a range of development goals are anticipated to increase in coming decades. Plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests (FSC, 1996).

In many cases, species selection directly determines the success of the plantation. Whether selecting species for a large-scale industrial plantation or a small-scale multipurpose tree plantation, a set of criteria is applied in various combinations. The criteria are determined by the purpose of the forest plantation such as, industrial or domestic uses, environmental protection, requirements of the local population, etc. and species are selected which are best suited to the site, in terms of climate and soil (Camirand, 2002).

The role of planted forests and permanent agricultural crops as sustainable and environmentally sound sources of renewable energy and industrial raw material should be recognized, enhanced and promoted. Their contribution to the maintenance of ecological processes, to off-setting pressure on primary/old growth forests, and to providing regional employment and development with the adequate involvement of local inhabitants should be recognized and enhanced (UNCED, 1992).

The XIII world forestry congress (WFC) in 2009 highlighted that in view of the growing global population and demand for forest resources, planted forests will become an increasingly important part of the landscape along with cities and towns, agricultural lands and indigenous forests. In its final communiqué the WFC stressed that planted forests provide the opportunity to produce more goods and services from less land and that they effectively contribute to climate change mitigation, degraded land restoration and other environmental benefits. Development and management of these forests need to be done within a sustainability framework that allows consideration of potential risks, such as pressure on other land uses and effects on water, and biodiversity along with the expected benefits (world forestry congress, 2009). First, the availability of land for forest planting on public or private lands must be known and second, the quality of the available land must be known to ascertain if it is appropriate to the objectives of the planned forest plantation. It is notorious that with all land capability classification systems, the classes of poor land, i.e., those with shallow soils and steep slopes, are earmarked for forestry production. This is because the main objective of most land capability classification systems is to map agricultural potential (of the land). However, the best soils for agricultural crops are also the best for industrial forest plantations (Camirand, 2002).

The general framework of forestry has dramatically changed during the past twenty years. Multi-objectivity is typical for current forestry. Forests should produce reasonable incomes while at the same time promoting conservation and recreational considerations. Criteria other than those related to wood production have been given more and more weight in the choice of management alternatives. In other words, forests are being used simultaneously for multiple purposes. This has lead to the need for methods that can be employed in planning of multiple purpose forestry. Particularly, decision-support methods are needed for the multiple-criteria evaluation and for the comparison of alternative forest plan (Kangas, 2005).

There is no single multi criteria technique able to solve all forest management problems and that none of the available methods is superior to the rest. Therefore, the selection of a particular method is driven by the type of information available and the specific characteristics of the problem. Goal programming technique proves most suitable when we deal with a set of conflicting objectives that need to verify some given thresholds or target values chosen by the decision-maker who must also provide his/her preferences regarding the achievement of such targets(Go´mez et al., 2006).

Additionally The Analytic Hierarchy Process (AHP), originally developed by Saaty (1977, 1980), is a widely used Multiple Criteria Decision Support (MCDS) method and perhaps the most popular in many fields, including natural resource management and the number of applications is continuously increasing (Vacik & Lexer, 2001). AHP has also gained interest among forestry practitioners.

In Iran, many of the vegetative communities include both endangered and endemic rare plant species. Hence, the protection of these species is essential in order to conserve genetic resources, soil, and water for maintaining an intact ecosystem. In addition, forest area per capita in Iran is 0.2 ha compared to the global standard of 0.8 ha (Shamekhi & Mirmohamadi, 2012). Therefore forest plantation is a common practice in order to restore the degraded forests in the Caspian region (Mohammadnezhad Kiasari et al., 2009).

There are many studies in Iran related to select appropriate species based on ecological properties (e.g. Malekghasemi & Babaei, 2005; Shamseh, 2010), but we could not find any study based on multi objective for species plantation selection.

The aim of this paper is to develop a sustainable plantation in terms of different criteria (ecological, economic, social and environmental) and several purposes (maximization of carbon content, maximization of Net Present Value (NPV) and maximization of job opportunity) simultaneously using multiple objective decision making methods (e.g. goal programming and Analytic Hierarchy Process) in order to specify appropriate plantation area for different species.

MATERIALS AND METHODS

Study area

This study was carried out in an Iranian Caspian forest atAstara region which is located in Guilan province around the west shore of the Caspian Sea. It consists of two watersheds and 13 districts with a surface area of 43,791 ha. The annual temperature ranges from 6.2 to 26.1 °C and an average annual rainfall is about 1500 mm (Fig. 1).There are annual pure species plantation by state in small groups including Persian maple (*Acer velutinum*), common ash (*Fraxinus excelsior*), basswood (*Tilia begonifolia*), caucasian oak (*Quercus castanifolia*), alder(*Alnus subcordata*), plum (*Prunus avium*)(native species), loblolly pine (*Pinus taeda*)and black pine(*Pinus nigra*) (exotic species) with a total surface area of 1757 ha that are suggested for plantation in the region by Iranian Forests Rangelands and Watershed Management Organization (FRWO).

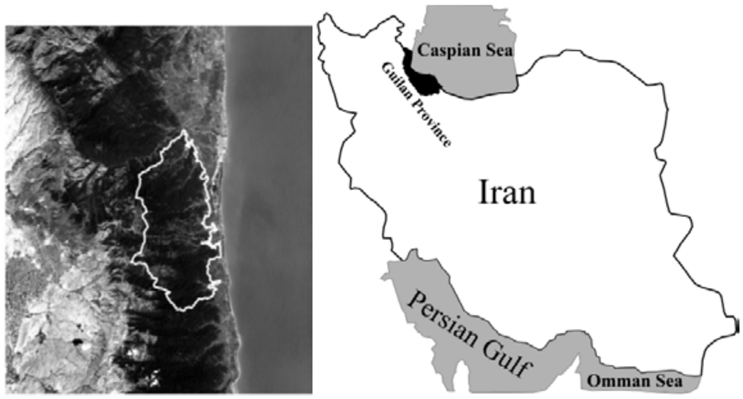

Fig 1. Location of the study area.

Method

To define the different criteria, variables and parameters for our model development, the following procedures were used:

Ecological capability evaluation of the area for plantation use

The ecological capability of the study area was evaluated for plantation use, based on multi-factor method and Specific Ecological Makhdoum Model by means of GIS tool (Makhdoum, 1993; Reyahi Khoram et al., 2005; Reyahi Khoram et al., 2013). Specific Ecological Makhdoum Model is a method which classifies regions or sites to relative homogeneous units (environmental units) with respect to ecological variables including elevation, aspect, slope, soil, vegetation and vegetation density layers and also considering the socio-economic aspects of the area under study (Makhdoum, 2011). All layers were digitized as a vector format and projected to the same coordinate system (UTM) on the scale of 1:25000 and then the related classification of each layer was done according to the applied model. The homogeneous ecological units map and land use map for plantation were extracted by overlaying and analyzing the layers. To investigate necessity of continuing plantation of present species, compatibility of each unit was determined with respect to the species ecological requirements.

Estimation of the aboveground biomass of per-hectare plantation

To estimate the total aboveground biomass and carbon content (50% of total biomass) (Losi et al., 2003; Pretzsch, 2010), stem volume and stem biomass were measured in terms of 62 rectangular plot measurements. The diameters (D) of all trees in each plot were measured and height (H) was determined by sampling in all diameter classes.The existing allometric equations from other countries were used to estimate crown biomass. Because of the lack of specific allometric equations for the selected tree species in Iran, allometric equations from other regions were evaluated and selected in terms of the geographical distribution of the sampled population, the number of sampled trees, the range of dimensions (D, H) of sampled trees, accounted dimensions and applied definitions (Rogreson, 1964; Snell et al., 1983; Johnnson, 1999; Johnnson, 2000; Yuste et al., 2005; Busing et al., 2005; Parker & Schneider, 1975; Gasparini et al., 2005).

Calculation of NPV

The NPV was calculated using stumpage price, harvesting cost, annual growth, interest rate and optimal rotating. Consumer price index was used for deflation. To estimate the stumpage price processes, models 1 and 2 were used and it was assumed that ε is a series of normally distributed errors with mean zero and autocorrelation zero. α and β are estimated parameters. Empirical data was used from the Iranian northern forests to estimate the parameters values of the model (Mohammadi Limaei, 2006).

$$P_{t+1} = \alpha + \beta P_t + \varepsilon_t \quad (1)$$

$$P\,eq = \frac{\alpha}{1-\beta} \quad (2)$$

The following function was used to determine the net present value (NPV):

$$NPV = \frac{P_{eq} \times \bar{g} \times t}{(1+i)^t - 1} \quad (3)$$

P_{eq}: Expected mean price process, $\bar{g}$: Annual growth, t: Optimal rotation, *i*: Interest rate.

Estimation of employment generation of per-hectare plantation

The required workforce needs for different plantation tasks were obtained from FRWO data base (FRWO, 2003).

Application of goal programming technique for multi objectives plantation

Goal programming provides a way of striving toward selected objectives simultaneously, treating them all in the same manner, although perhaps giving them different weights. Representing some goals by constraints in effect gives them priority over the goal reflected in the objective function, because the objective function is optimized within the feasible region defined by the constraints. Goal programming attempts to correct these limitations while retaining the useful basic structure and numerical solution of linear programming.

The objective function of a goal programming problem contains some or all of the goal variables. The general purpose of the objective function (Equation 4) is to make the total deviation from all goals as small as possible (Buongiorno & Gilless, 2003).

$$\min \sum_{i=1}^{G} (W_i^- D_i^- + W_i^+ D_i^+)$$

(Kangas et al., 2008) (4)

And all or some of the management goals are expressed by goal constraints:

$$\sum_{i=1}^{n} a_{ij} x_j + D_i^- - D_i^+ = G_i, \quad i = 1, \dots G \quad (5)$$

where:

Xj is the jth activity (decision) variable. *aij* is the (constant) contribution to goal *i* per unit of activity *j*. *gi* is a constant measuring the target of goal. *i*, of which there are *G*. *d*+, *d*- are deviations from the goal. W^+, W^- are the weights per unit of eviations.

In this research, the goal programming technique was applied using objective function, constraints, and weights in 4 different ways. Different weights for purposes based on decision maker's judgments using AHP approach, the changing of the weighting factors was accomplished by, changing the sign = to ≥ in defining constraints in model 2 and using ordinal weights instead of cardinal weights. Lingo software version 10 was used to run the models.

RESULTS

Evaluation of ecological capability for plantation use

Results showed that 36 out of 329 environmental units (equal to 2,597 ha) were appropriate for plantation. The ecological capability map of the area for plantation was drawn (Fig. 2) and coincided with ecological species requirements; the predicted area for each given species was specified (Table 1). Plum was shown not to be ecologically adapted to the areas studied and was not analyzed further.

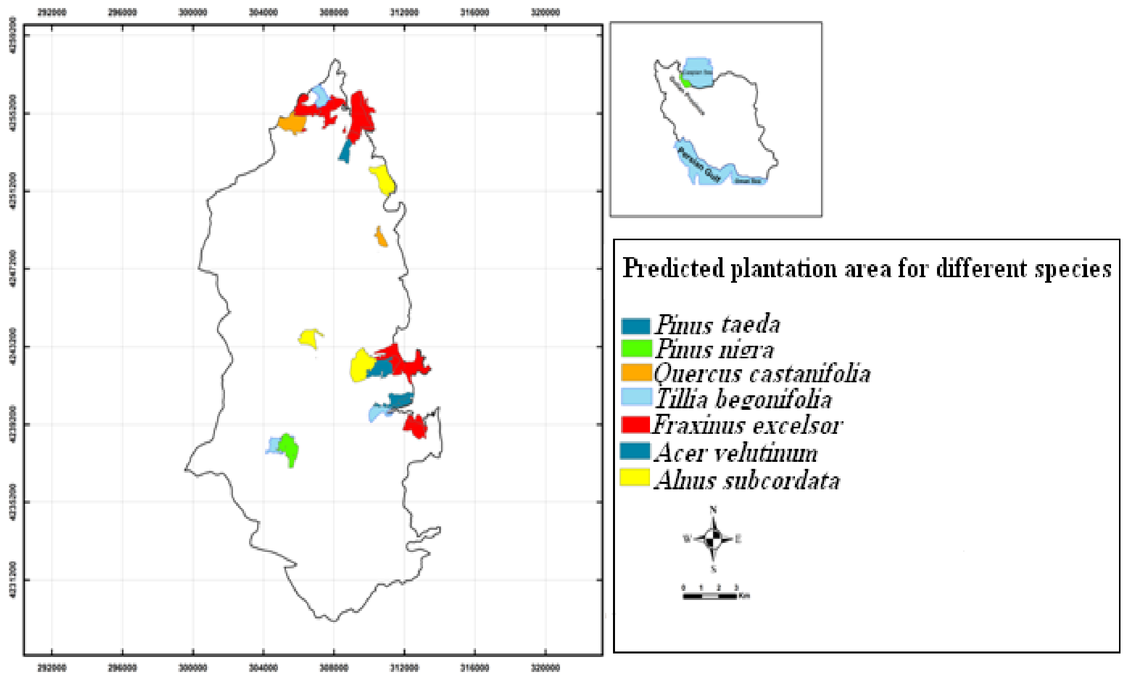

Fig 2. Predicted plantation area for different species based on species ecological requirements.

Table 1. Predicted plantation area for different species

species	Predicted area for plantation (ha)
Alnus subcordata	976.03
Acer velutinum	872.46
Quercus castanifolia	348.15
Tilia begonifolia	346.26
Pinus taeda	235.67
Fraxinus excelsior	165.47
Pinus nigra	149.11
Prunus avium	0
Total	**3093.15**

Total above ground biomass and carbon content of different species

According to the defined method (species-specific allometric equations), total aboveground biomass was calculated as a product of tree components and was reported as stem biomass, crown biomass and total aboveground biomass.The amount of carbon content was also calculated for different species (Table 2).

Table 2. Mean values of stem, crown and total biomass of different species in t/ha.

Species	Stem biomass (t/ha)	Crown biomass (t/ha)	Total aboveground biomass (t/ha)	Carbon content(t/ha)
Alnus subcordata	93.18	10.35	103.53	51.765
Acer velutinum	70.16	19.88	90.03	45.015
Quercus castanifolia	59.61	13.21	72.82	36.41
Tilia begonifolia	57.70	14.18	71.88	35.94
Fraxinus excelsior	44.28	11.79	56.07	28.035
Pinus taeda	121.02	20.74	141.76	70.88
Pinus nigra	15.73	4.31	20.05	10.025
Total				**278.07**

NPV for different species

NPV was calculated from field measurements data. Empirical datafrom the Iranian northern forests and FRWO data base was used to obtain annual growth, expected mean price process and optimal rotation age, respectively. Interest rate was assumed 5 %(Table 3).

Labour requirements for plantation activities According to data collected via FRWO of Iran, the labour requirements for different the plantation items are (Table 4). To calculate the number of workforce required for plantation, different items were totalled for each tree species. Then 110 labour per day per ha was considered for every species except for oak and maple the number of labour were considered 120 and 115, respectively.

Table 4. Labour requirements for individual plantation activities (FRWO, 2003)

Operational	Activity	labour(day/ha)
Site preparation	Screefing	13
	Fencing	13
	Planting site preparation[1]	20
	Planting seedlings	14
	Seedling production	20
On-going silvicultural operations	Soil crust break-up	10
	Weeding	8.5
	Replanting[2]	11.5
Seed collection, preparation and planting	Oak	10
	Maple[3]	5

[1] Actual hole digging for seedling planting
[2] Includes seedling production, planting and site (hole) preparation
[3] Includes scarification

Definitions of objective function and constraints

According to 3 specific purposes we defined 4 different models in terms of the same priority for all purposes, different weights were assigned, based on decision maker's judgments using AHP approach, changing sign = to ≥ in defining constraints in model2 and Using ordinal weights instead of cardinal weights as per the discussion in Section 2.2.5.

$\mathrm{Max} \sum_{i=1}^{7} (C_i \times X_i)$ Maximization of carbon content per hectare plantation. (5)

$\mathrm{Max} \sum_{i=1}^{7} (NPV_i \times X_i)$ Maximization of net present value per hectare plantation. (6)

$\mathrm{Max} \sum_{i=1}^{7} (WF_i \times X_i)$ Maximization of required labour per hectare plantation. (7)

So, the multiple objective problems were formulated as linear models:

Carbon function and coefficients were defined as carbon content per hectare plantation for each species divided by predicted plantation area for related species.

$$0.046X_1 + 0.148X_2 + 0.032X_3 + 0.244X_4 + 0.217X_5 + 0.3X_6 + 0.028X_7 + d_8^- - d_8^+ = 278.06 \quad (8)$$

NPV function and coefficients were defined as net present value per hectare plantation for each species divided by predicted plantation area for related species.

$$14.66X_1 + 98.51X_2 + 4.887X_3 + 16.22X_4 + 68.54X_5 + 122.72X_6 + 8.96X_7 + d_9^- - d_9^+ = 98660.91 \quad (9)$$

Labour function and coefficients were defined as required labour per hectare plantation for each species divided by predicted plantation area for related species.

$$0.117X_1 + 0.315X_2 + 0.126X_3 + 0.804X_4 + 0.664X_5 + 0.466X_6 + 0.317X_7 + d_{10}^- - d_{10}^+ = 785 \quad (10)$$

Subject to:

$X_{Ac} + d_1^- - d_1^+ = 976.03$

$X_{Al} + d_2^- - d_2^+ = 348.15$

$X_{Fr} + d_3^- - d_3^+ = 872.46$

$X_{Qu} + d_4^- - d_4^+ = 149.11$

$X_{Ti} + d_5^- - d_5^+ = 165.47$
$X_{Ta} + d_6^- - d_6^+ = 235.67$
$X_{Ni} + d_7^- - d_7^+ = 346.26$
$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 \leq 3093.15$
$X_1 + X_3 + X_5 \leq 976.03$
$X_1 - X_3 \leq X_5$
$X_1 - X_5 \leq X_3$
$X_6 + X_7 \leq 346.26$
$X_1, X_2, X_3, X_4, X_5, X_6, X_7, d_{1..7}^+, d_{1..7}^- \geq 0$
(11)

where:
X_1 to X_7: The predicted plantation area for different species based on ecological capability evaluation.
C_i: The amount of carbon content per hectare plantation for different species.
NPV$_i$: Net present value per hectare plantation for different species.
WF$_i$: Workload or labour requirements per hectare plantation for different species.
d+, d- : Deviations from the goal.

Model 1
To simplify the choice of weights, it is best to reduce the objective function to the simplest expression consistent with the problem at hand. The difficult task of choosing weights can also be simplified by working with relative deviations from the goals. Where, the weights now express the relative importance of deviating by one percentage point from the corresponding goals. The coefficients are very small so we multiply all the coefficients by the same large number, say10, 000, which will not change the value of the variables in the best solution (Buongiorno and Gilless, 2003).

$$\min z = \frac{w_1}{976.03} d_1^+ + \frac{w_2}{348.15} d_2^+ + \frac{w_3}{872.46} d_3^+ + \frac{w_4}{149.11} d_4^+ + \frac{w_5}{165.47} d_5^+ + \frac{w_6}{235.67} d_6^+ + \frac{w_7}{346.26} d_7^+ + \frac{w_8}{278.06} d_8^- + \frac{w_9}{98660.91} d_9^- + \frac{w_{10}}{785} d_{10}^- \quad (12)$$

Based on the same priority for all purposes we assumed $w_1, .. w_{10} = 1$ and Model 1 was defined as the following function:

$$\min Z = 10.2d_1^+ + 28.7d_2^+ + 11.4d_3^+ + 67d_4^+ + 60.4d_5^+ + 42.4d_6^+ + 28.8d_7^+ + 35.9d_8^- + 0.1d_9^- + 12.7d_{10}^- \quad (13)$$

Model 2
To express the relative importance of each goal we applied different weights for purposes based on decision maker's judgments by use of analytical hierarchy questionnaire with acceptable validity and reliability. Expert Choice software was used to analyze the collected data (Fig. 3). Then Model 2 was defined based on the new weights for all of the variables.

$$\min Z = 1.82d_1^+ + 5.13d_2^+ + 2.029d_3^+ + 10.38d_4^+ + 8.87d_5^+ + 3.90d_6^+ + 2.016d_7^+ + 18.129d_8^- + 0.0352d_9^- + +1.828d_{10}^- \quad (14)$$

Model 3
To achieve to the least constant goal value based on 3 defined purposes without any positive or negative deviations the sign = was changed to ≥ in defining our functions.

Model 4
In this model it is assumed that decision makers are only able to rank the goals in order of importance without weighting them. Ordinal weights are used. In this analysis, the maximization of carbon content per hectare (Goal 1), maximization of NPV per hectare (Goal 2) and maximization of workforce labor required per hectare (Goal 3) were ranked respectively. This analysis requires that all available resources be allocated to achieve Goal 1 prior to moving to subsequent goals. After the attainment of Goal 1, any remaining resources must be used on Goal 2 to maximize achievement of this goal. Any resources remaining after attainment of Goals 1 and 2 are allocated to Goal 3.

$\min Z = d_8^-$
Subject to:
$0.046X_1 + 0.148X_2 + 0.032X_3 + 0.244X_4 + 0.217X_5 + 0.3X_6 + 0.028X_7 + d_8^- - d_8^+ = 278.06$

$\min Z = d_9^-$
Subject to:
$14.66X_1 + 98.51X_2 + 4.887X_3 + 16.22X_4 + 68.54X_5 + 122.72X_6 + 8.96X_7 + d_9^- - d_9^+ = 98660.91$
$0.046X_1 + 0.148X_2 + 0.032X_3 + 0.244X_4 + 0.217X_5 + 0.3X_6 + 0.028X_7 + d_8^- - d_8^+ = 278.06$
$d_8^- + d_8^+ = D_1$ (15)

$$\min Z = d_{10}^-$$

Subject to:

$$0.117X_1 + 0.315X_2 + 0.126X_3 + 0.804X_4 + 0.664X_5 + 0.466X_6 + 0.317X_7 + d_{10}^- - d_{10}^+ = 785$$

$$14.66X_1 + 98.51X_2 + 4.887X_3 + 16.22X_4 + 68.54X_5 + 122.72X_6 + 8.96X_7 + d_9^- - d_9^+ = 98660.91$$

$$0.046X_1 + 0.148X_2 + 0.032X_3 + 0.244X_4 + 0.217X_5 + 0.3X_6 \quad + 0.028X_7 + d_8^- - d_8^+ = 278.06$$

$$d_8^- + d_8^+ = D_1$$

$$d_9^- + d_9^+ = D_2$$

The models were run using Lingo10. Model 1 and Model 4 have identical results. Using goal programming technique and changing the weights and coefficients created different solutions that help decision makers to choose the optimal solution (Fig. 4).

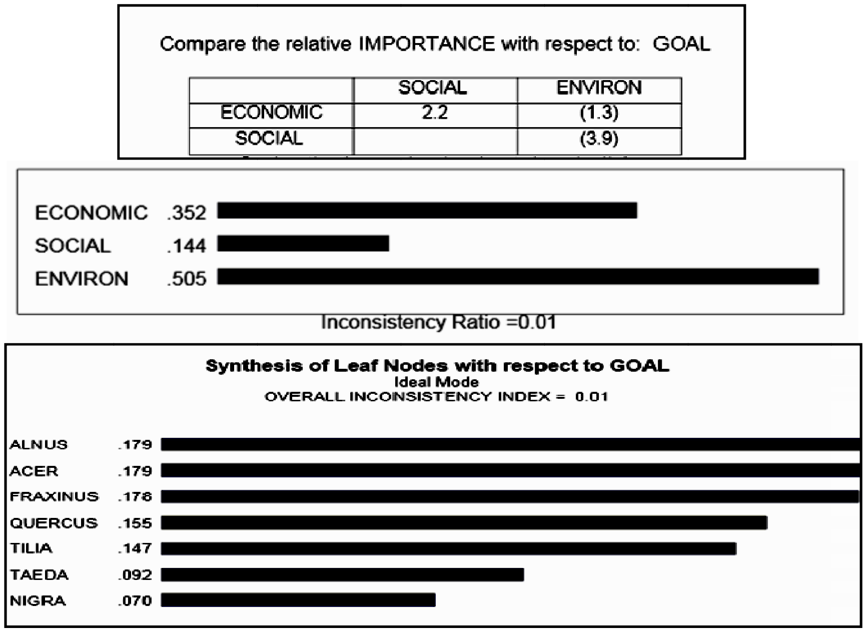

Fig 3. The weights obtained by decision makers judgments using AHP

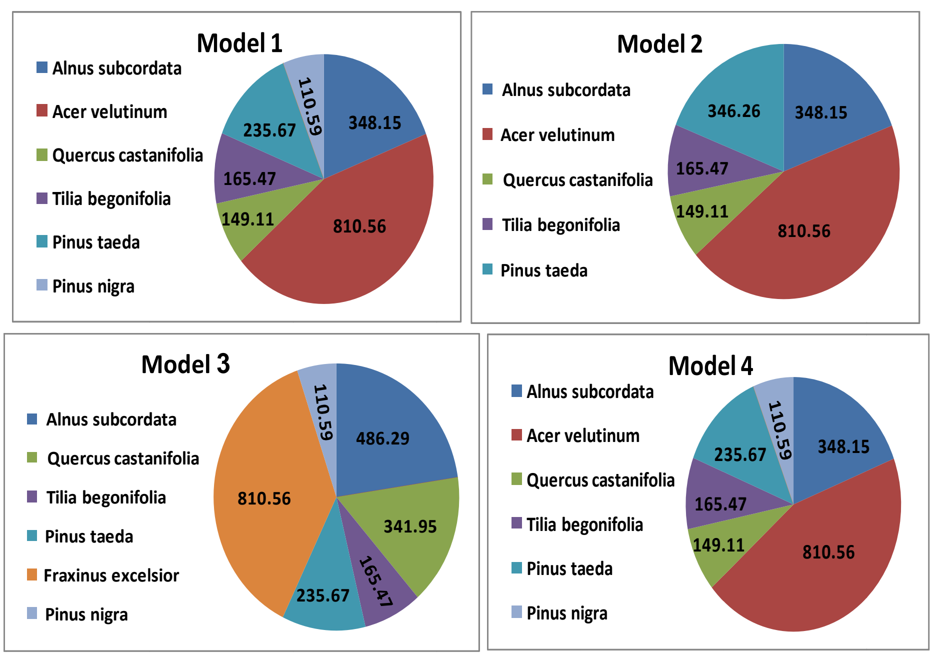

Fig 4. Modeling output for plantation areas by species at 4 scenarios.

DISCCUSION

Plantations provide not only wood, fiber, food and fuel, but also other non-wood forest products. Plantations can also sequester carbon, rehabilitate degraded lands, assist in restoring landscapes, protect watersheds and agricultural soils, provide recreational areas and amenities and provide for local economic development

There has been lack, particularly in developing countries, of knowledge, capacity and capability, to provide appropriate enabling forest laws, regulations, policies, plans and technical support systems. This has led to forest investments in plantations that have caused land-use, social and environmental conflicts. Other outcomes have included degraded forest health, and productivity and lower than expected returns on investment (FAO, 2009).

This study investigated the development of sustainable plantation in terms of different criteria and several purposes simultaneously using multiple objective decision making methods in order to specify appropriate plantation area for different species.According to the results and the current situation of plantation in the area, there has been a lack of established forest plantation principles to effectively create sustainable management of forest plantations in Iran.

This study showed the potential to modify the management of forest plantations using the new described methods . If only ecological methods were used, the results would ignore the multi-objective goals of the plantation.

Previous studies have shown the applicability and power of using the modeling systems analyzed in the present study. Sen and Nandi (2012) found that the goal programming appears to be an appropriate, powerful and flexible technique for decision analysis of the modern decision maker who is charged with achieving multiple conflicting objectives under complex environmental constraints. The modeling approach does not attempt to maximize or minimize the objective function directly as in the case of conventional linear programming. Goal programming model seeks to minimize the deviations between the desired goals and the actual results to be obtained according to the assigned priorities.

Díaz-Balteiro and Romero (2004) have proposed a method based upon goal programming that turns out to be a powerful tool for determining the overall sustainability attached to each forestry system. The results obtained can be extended in different directions. One potential extension involves determining the preferential weights attached to each sustainability indicator. They found two possible complementary rather than alternative procedures for addressing the problem.

The use ofmathematical techniques and changing the weights and coefficients created different solutions that can assist decision makers in selecting the optimal solution. Giménez et al. (2013) proposed a sequential procedure under a multi-criteria framework to address sustainable management in industrial forest plantations. The results showed the validity of the goal programming approach, thus deriving the most sustainable management alternative under each scenario.

The present methodology allowed for the consideration of different preferential weights for selected sustainability indicators we examined four models. Model 1 and Model 4 had identical results. Models 2 and 3 differed in their results. If we assume that the total current plantation area for management cannot be modified, the best solution is related to Model 1 with the appropriate plantation area for each species being Persian maple (810 ha), alder (348 ha), loblolly pine (235 ha), basswood (165 ha), caucasian oak (149 ha), black pine (110 ha) and common ash (0 ha).

This research presented a modeling approach based on linear goal programming. The models consider area control regulation strategies about several problems associated with the management of plantations. The results showed that the models provided better guidelines for species composition, and the profitability of the plantations and better allocation of resources than the current management plans. Diaz-Balteiro et al. (2009) showed that the goal programming models provided more flexible harvest schedules, and the profitability of eucalypt plantations was 64% higher than that under the current management plan.

These findings indicated that, we can modify current plantations and plan for future plantations to increase not only forest productivity, but as importantly achieve desired economic, environmental and social outcomes in a multi-objective forestry program.

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روش‌های برنامه‌ریزی آرمانی و تحلیل سلسله مراتبی برای توسعه جنگلکاری پایدار

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چکیده

هدف از این تحقیق توسعه جنگلکاری پایدار و بهینه بر اساس روش‌های ریاضی برنامه‌ریزی آرمانی و تحلیل سلسله مراتبی(AHP) می باشد. منطقه مورد مطالعه در شمال ایران، استان گیلان واقع گردیده است. به منظور انجام این مطالعه ابتدا توان اکولوژیک منطقه برای کاربری جنگلکاری بر اساس مدل اکولوژیک مخدوم که روش ارزیابی چند عامله می باشد و با استفاده از GIS تعیین شد. سپس به منظور بهینه‌سازی از تکنیک ریاضی چند هدفه برنامه ریزی آرمانی استفاده شد که این اهداف شامل اهداف اکولوژیک، اقتصادی و اجتماعی بودند. میزان موجودی کربن به عنوان شاخص اکولوژیک در نظر گرفته شد و برای اندازه‌گیری بیوماس کل رویه زمینی و به تبع آن موجودی کربن، ابتدا حجم درخت و سپس بیوماس تنه درخت اندازه گیری شد و در ادامه به منظور محاسبه بیوماس تاج درختان از معادلات آلومتریک موجود استفاده شد. به منظور دستیابی به هدف دوم، ارزش خالص فعلی به عنوان شاخص اقتصادی در نظر گرفته شد و برای محاسبه آن از قیمت چوب گونه‌های مختلف، هزینه‌های بهره برداری، شاخص قیمت مصرف کننده، رویش متوسط سالیانه، نرخ سود و سن بهینه بهره برداری استفاده شد. تعداد کارگر لازم برای انجام جنگلکاری به تفکیک آیتم‌های مختلف به عنوان شاخص اجتماعی و برای دستیابی به هدف سوم، در نظر گرفته شد و داده‌های موجود از سازمان جنگل‌ها و مراتع کشور تهیه شد. برای در نظر گرفتن تمامی اهداف به طور همزمان از تکنیک برنامه‌ریزی آرمانی استفاده شد. نتایج نشان داد که با استفاده از مدل‌های ریاضی نسبت به استفاده از مدل های اکولوژیک به تنهایی نتایج منطقی و مطلوب‌تری بدست خواهد آمد. همچنین توانایی وزن‌دهی به متغیرها در مدل‌های ریاضی به تصمیم گیرندگان و مدیران اجازه میدهد تا از بین جواب‌های مختلف راه حل بهینه را انتخاب کنند. در نهایت با استفاده از این مدل مساحت مناسب برای کاشت گونه‌های پلت، توسکا، کاج تدا، نمدار، بلندمازو، کاج سیاه و زبان گنجشک به ترتیب 810، 348، 235، 165، 149، 110 و صفر هکتار بدست آمد.

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