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USING MULTIPLE TECHNIQUES FOR THE BEST UTILIZATION DECISION IN ZAKHO POPLAR STANDS

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Abstract

In the current research we used the Dynamic Programming approach to address the problems of rotation age and thinning of utilization for *Populus nigra* L. of Zakho stands. We considered different harvest systems, including clear-cut with or without thinning, at various stand ages. We aimed to select the best option combination that would lead to the most rewarding decision to reach our goals. We analyzed the possibility of thinning at different ages, including 3, 4, 5, 6, 7, 8, and 9 years, using thinning of 20% of all stands. The final harvest was conducted at the age of 10 years. We considered 7 possible combinations of thinning operations and also one final harvest as a possible blende. The results of our analysis provide the best alternative options for each of the 8 proposed stages and also enable us to calculate the net revenues of each path route, which were determined as high revenue in the stage 9 from node 1 to node 10 of route 1-10, and the highest revenue was in the stage 5 from node 1to node 6 of route 1-6.

Keywords: Dynamic Programming, Forest Harvesting, Thinning, Zakho Stands, *Populus nigra* L.

INTRODUCTION

Poplar (*Populus nigra* L.) is a fast-growing tree species that is widely distributed in the northern part of the Iraq. It is highly valued for its high productivity and numerous benefits. Poplar stands are a significant source of wood for various industries, including the manufacture of sticks, paper products, tables, boxes, compressed wood, and in the building industry. The abundance of poplar stands in Iraq makes it an attractive option for farmers looking to establish and plant large areas.

However, due to the lack of proper management, the stands can deteriorate and suffer from the effects of weather factors, which call for the need to optimize alternative of utilization processes, which refer to the operation of harvesting trees. In this research study we depended on the dynamic programming which is approach method for testing many alternatives to select the best alternative option which is beneficial for our project.

The forest stands management is currently inadequate, and harvesting whole trees at the end of the rotation period is not the most efficient approach. Instead, it may be more beneficial to cut progressively over the rotation period, leading to a progressive thinning of the stand before the final harvest.

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Forestry managers and natural resource experts must balance conflicting goals, such as economic, environmental, social, cultural, technical, and aesthetic goals, when developing land management plans. This is a challenging task, as determining the optimal blend of management uses from many goals is complex. (Steiguer J. et al 2003)

Dynamic Programming (DP) is a powerful tool for selecting the best alternatives that meet the decision maker's goals and the objective of this research. The goal of the research was to understand the fundamental principles of DP and its various methods, such as recursive and other approaches, for optimizing stand-level operations.

To achieve this, the best alternative between clear cutting and thinning in different age groups of the selected stand was evaluated based on the objectives of the DP operation. The objective of the DP operation is to determine the longest or shortest path through the network, and within a network, the shortest paths are linked to minimizing goals, while the longest paths relate to maximizing a goal.

Dynamic Programming has been applied in various ways to optimize the potential mean annual increment (MAI), economic and soil expectation value (SEV) of tree stands, and develop a systematic approach for making optimal decisions. This method is also useful for solving dynamic systems of equations numerically.

Dynamic Programming can be used to address a wide range of problems, not only those related to natural resource management, but also various business and industrial applications. Kennedy (1986) highlighted the versatility of Dynamic Programming.

In the past, the use of "derivatives" was the go-to method for determining the optimal harvest age of an even-aged forest stand. This approach aimed to maximize the net present value (NPV) of an infinite series of timber regeneration, growth, and harvest periods. This was considered a classic stand-level optimization problem in forest economics.

However, Faustmann (1849) pointed out that when only timber values were taken into account and no stochastic program was applied, the solution was usually imputed with the first available method. Samuelson (1976) proposed various mathematical specifications for the problem, while Hartman (1976) expanded the model to include values associated with standing trees, such as wildlife and habitat, as well as the value of harvested timber. Despite this, the Faustmann formulation could still lead to a false optimal solution when using stochastic programs, as noted by Lembersky and Johnson (1975) and Buongiorno (2001).

Arimizu (1958) applied Dynamic Programming (DP) to solve a sequential optimization problem in forestry. DP is a powerful method for optimizing complex problems by breaking them down into smaller, simpler subproblems. It has been widely used in a variety of fields, including forestry. Arimizu was the first researcher to apply operational research techniques, which were later known as Dynamic Programming, to stand-level forest planning, and was influenced by the work of Bellman and Dreyfus, the founders of Dynamic Programming.

Gerard F. (1968) stated that Dynamic Programming is a powerful tool that can handle both discrete and continuous variables, which may explain its popularity in cases of uncertain

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variables. However, it is important to exercise caution when using Dynamic Programming, as the number of calculations required increases exponentially with the number of state variables and stages.

This means that the number of calculations increases not only by the number of state variables, but also by the number of stages, and by a multiplicative amount for each additional constraint related to state and decision variables. In general, it is believed that a state variable is required at each stage for each constraint that relates to state and decision variables.

Dynamic Programming has been widely used in forest management for many years. Early applications focused on using DP to schedule silvicultural operations or manage timber in even-aged stands within the classical framework (Amidon and Akin, 1968; Hoganson and Rose, 1984). These approaches used DP for intermediate operations and optimal forest rotation ages (Brodie et al., 1978; Arthaud and Pelkki, 1996).

Schreuder (1971) used dynamic programming to solve an optimal thinning and rotation age problem. He formulated the problem in the form of calculus of variation but was unable to find a specific solution form. However, when he registered the problem in the dynamic programming form, he was able to obtain a numerical solution. Brodie *et al.* (1978) developed a method to find the optimal thinning schedule and rotation period length using forward the recursion.

They found that forward recursion was very flexible for thinning analysis but did not take into account very intensive thinning to increase the growth of the diameter. Brodie and Kao (1971) solved the problem using a biometric model and dynamic programming. They found that the integration of dynamic programming and stand growth and yield models allowed for the simultaneous determination of the timing and intensity of thinning. To successfully integrate dynamic programming and stand growth and yield models, one must limit the number of variables used to define thinning decisions.

Haight et al. (1985) noted that the successful integration of dynamic programming and stand growth and yield models have been well modeled specifically for timber harvesting problems such as the rotation period and thinning operation problems.

The objectives of these problems are to find the optimal stand replacement rotation periods or the optimal partial harvesting of thinning periods for a stand or stands. The net return is maximized for either the rotation age or thinning problems.

To obtain more accurate solutions, Dynamic Programming (DP) can be utilized by making optimal management decisions on a frequent basis. The ability to evaluate the forest after a shorter period of time allows for the opportunity to adjust management decisions as the forest changes. By breaking down the larger problem into several smaller problems, Winston (2004) suggests that this approach can be more effective.

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In another study, Diaz and Rodriguez (2006) applied dynamic programming within the classical framework to analyze optimal coppice management strategies for fast-growing species in both Brazil and Spain.

Yoshimoto and Marušák (2007) optimized timber and carbon values in a forest stand using dynamic programming with MSPATH, considering both the thinning and the final harvest.

Asante et al. (2011) applied the B classical dynamic programming technique to determine the optimal harvest decision for a forest stand that provides both the timber harvest volume and carbon sequestration services, without considering intermediate activities such as thinning. Asante and Armstrong (2016) used dynamic programming to determine the optimal harvest decision for a forest stand in the boreal forest of western Canada that provides both timber harvest volume and carbon sequestration services, without considering intermediate operations such as thinning.

Kuloglu (2012) conducted a study that improved a dynamic programming model to find the optimal stand management policy for timber harvest and carbon sequestration. The forest stand was described based on age and the amount of carbon stored in the dissolved organic matter (DOM pool). The study examined the sensitivity of the optimal harvest age to the stocks of carbon in dead organic matter and carbon prices.

The present dynamic programming model was used to examine the net present value of the forest stand age, stocks of carbon, and carbon prices. Additionally, the study presented a dynamic programming model to examine the protected trajectories of carbon stocks in DOM given optimal harvest rules for a given carbon price, and the impact of ignoring carbon stocks in DOM on the decision of optimal harvest.

The goal of stand level optimization is to create the best management plan for each individual forest stand, without considering the management of other stands in the forest. The planning process involves analyzing various intermediate operations, such as thinning, and determining the best timing and intensity of silvicultural activities, as well as the optimal stand structure. While stand level decisions can improve options for forest level problems, they are not influenced by decisions made for other stands or the conditions of the surrounding forests.

According to Bettinger *et al.* (2009), one disadvantage of using dynamic programming in this process is that the shadow prices, which are usually provided by linear programming, are often lacking or inadequate measures of sensitivity. Additionally, defining reasonable stages and states can be challenging, especially if the intervals between stages are long and the range of states is large. The unpredictability of future conditions and events is also a major drawback of optimization operations, and any modelling assumptions made are considered static. This can limit the accuracy of the optimal solution of the study.

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MATERIALS AND METHODS

This study was conducted in the *Populus nigra* L. stands in the Zakho Duhok/ Kurdistan Region of Iraq, which is located at a latitude of 42°28'22.00" E and a longitude of 37°8'0" N, rising above sea level at a rate of 433.5m. The stands are situated in a mountainous region of Iraq and are located in secure areas of rain, making them one of the agricultural areas with fertile soil.

The plantation covers an area of approximately 200 hectares and is located on the east bank of the Heizl River, 15 km from the center of the town of Zakho. The stands were selected for their fast-growing characteristics and because of their importance in the location. A stand of *Populus nigra* L. was selected for the empirical implementation from the Zakho forest, after a field survey of the selected stands. The stands were aged for 9 years, as shown in Table 1.

Table 1: Is the yield table for the stands of *Populus nigra* L. in Zakho.

Stand Age (year)	Yield (m^3/ hectare)
2	54.841
3	151.233
4	112.258
5	555.292
6	942.503
7	552.560
8	802.701
9	957.318
10	1198.010

This study focuses on the utilization of an existing *Populus nigra* L. stand in the Zakho Duhok/ Kurdistan Region of Iraq. The study explores various decisions that can be made regarding the stand, such as whether to cut it down and start a new timber stand, or perform a thinning now or in the future.

The final harvest may also be delayed for a few more years, followed by the establishment of the next timber stand. It is also possible to consider multiple thinning stages before the final harvest, with the goal of maximizing the value of the forest (FV) by selecting the optimal alternative for the existing stand. The study will begin with multiple suggestions, such as clear cutting for the selected stand or using a thinning treatment for multiple stages along the age of the trees, eventually reaching clear cutting at the end of the rotation age.

One thing that stands out immediately is the sheer number of options to consider when it comes to the thinning age and intensity. When multiple thinning processes are involved, the combinations quickly multiply. For instance, let's say we're considering thinning at either age 3 or 4 years, with a thinning percentage of 20% of the trees of the stand. Then, we can move on to the second thinning, which can happen at ages 5, 6, 7, 8, or 9, using the same thinning percentage as the first.

Finally, we can decide on the harvest age, either 6 or 10 years after the first thinning. With 9 possible combinations for both the first and second thinning, and just one possibility for the

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final harvest, a total of 81 possible combinations to consider. To determine the best combination, one possible solution is to use the Dynamic Programming technique to solve the problem, we break it down into distinct stages. In the first two stages, only site preparation and tree planting are involved. From stage three to stage nine, we perform inch thinning at ages 2, 3, 4, 5, or 6 years, thinning at ages 7, 8, 9, and finally a final harvesting (clear cutting) at age 10.

The problem is broken down into stages, with each stage having a state variable that describes the current status of the problem and an action variable that corresponds to a particular decision or action. The payoff function represents the benefits associated with that action. The technique of solving sequential decision-making problems using dynamic programming involves selecting the right variables as the state and action variables. This makes the problem formulation and solution straight forward.

For the study, there are several options for utilizing the stands, including not harvesting the forest by clear cutting until it reaches the optimum economic rotation age of 10 years in this location. The goal is to maximize the value of the investment. **And the options considered for this research study were included as follows:**

1. No action was taken before or after clear-cutting at the suggested age (6 years).
2. No action was taken before or after clear-cutting at the end of the suggested age (10 years).
3. Thinning at age 3 years, from below, using 20% of the stand and then thinning again at age 5 years, from below, using 20% of the stand.
4. Thinning at age 4 years, from below, using 20% of the stand and then thinning again at age 6 years, from below, using 20% of the stand.
5. Thinning at age 5 years, from below, using 20% of the stand and then thinning again at age 7 years, from below, using 20% of the stand.
6. Thinning at age 5 years, from below, using 20% of the stand and then thinning again at age 8 years, from below, using 20% of the stand.
7. Thinning at age 6 years, from below, using 20% of the stand and then thinning again at age 8 years, from below, using 20% of the stand.
8. Thinning at age 4 years, from below, using 20% of the stand and then thinning again at age 9 years, from below, using 20% of the stand.

We have considered eight alternatives that can determine the one that provides the highest **net return**. In practice, many of these alternatives may be evaluated for individual stands. However, we limited this analysis to provide a balance between illustrating the technical detail of dynamic programming and providing a realistic decision on the utilization of our stands. The alternatives can be evaluated using dynamic programming (DP). A network of the stages linked to the problem, can be designed to visualize the transitions linked to the structure of the stand over time, as shown in Fig. (1).

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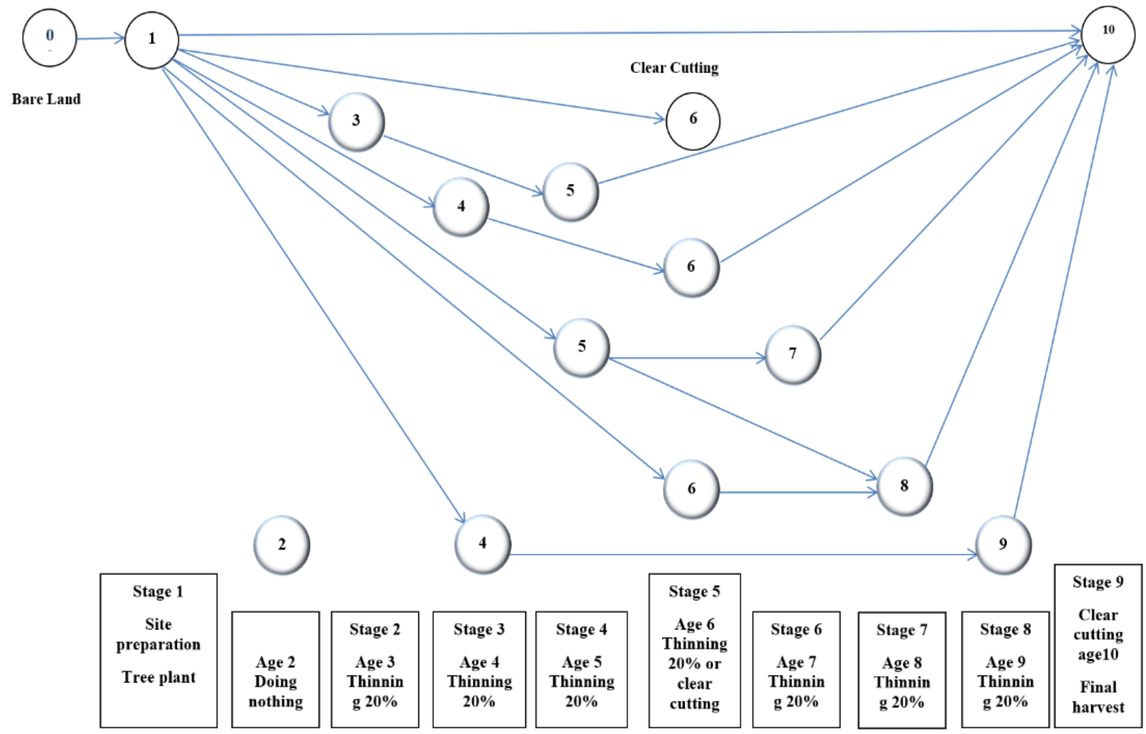

Figure 1: Illustrate the network of options for utilization decision of Poplar stand in Zakho, including nine possible stages

Depending on the fig (1) above, the Nodes 2-3 are the first start thinning option. And the nodes 4, 5, or 6, 7, 8, 9 represent another thinning option. As we mentioned, dynamic programming will be applied to solve the problem of this research. This requires the estimation of discounted costs, revenues, and the net discounted revenues, which are estimated based on the yield table, and the discount rate of 8% with the stumpage price of 350000 ID/m^3, as shown in Table (2). Then the process needs to calculate the Net Revenues with some management alternatives for the stand, which are shown in the table (3) below.

Table 2: Illustrate Net discounted revenues for *Populus nigra* L. stand in Zakho (ID)

Stand age (Years)	Discounted Revenues	Discounted Costs	Net Discounted Revenues
2	9162808.642	1037379.973	8125428.669
3	22574604.35	5001143.118	17573461.24
4	17365080.27	4777694.043	12587386.23
5	87093381	850728.9963	86242652
6	127546332.5	2205593.694	125340738.8
7	59588956.62	1166980.791	58421975.83
8	81546834.75	2971478.865	78575355.89
9	82188560.38	3501742.77	78686817.61
10	95047303.75	6947902.321	88099401.43

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Table 3: Illustrate the discounted Revenues, Costs Associated with Net Revenues with many Management options for utilization of *Polulus nigra* L. Stand in Zakho, between two nodes

From node	To node	Volume harvested (m^3/ha)	Net Revenues r (a – b)	Nodes
1	10	1198.081	187282259	1-10
1	6	942.503	205672274	1-6
1	3	151.2335	37017767	1-3
3	5	525.045	124217153	3 -5
5	10	1087.0227	169277740	5 -10
1	4	112.2582	24101901	1- 4
4	6	920.0513	200720341	4 - 6
6	10	1009.5804	156722971	6 -10
1	5	555.2915	131421994	1-5
5	7	441.5013	88997138	5 -7
7	10	1087.5690	169366305	7-10
5	8	691.6425	127814044	5 - 8
8	10	1037.5408	161255847	8 -10
6	8	614.2002	113170161	6 - 9
4	9	934.8661	160181288	4 - 9
9	10	1006.6174	156242616	9 -10

Table 4: Illustrate the discounted Revenues, Costs Associated and Net Revenues with Management options for utilization *Populus nigra* L. Stand in Zakho, for all recursion (Path or routes)

From node	20% Thinning in Age	To node	Volume harvested (m3/ha)	N_t Revenue
1	----	1-10	1198.08	187015922.5
1	----	1- 6	942.503	205309926.1
1	3-5	3-5-10	1056.78	160610799.6
1	4-6	4-6-10	987.129	148184897.8
1	5-7	5-7-10	976.511	149590071.6
1	5-8	5-8-10	926.029	139784916.3
1	6-8	6-8-10	849.04	126261498.4
1	4-9	4-9-10	984.166	146083382

RESULTS AND DISCUSSION

Depending on the data provided in Tables (3) and (4), where the discount rate is 8% and the stumpage price is 350000 ID/m^3. At stage (3), a final harvesting was implemented. In the stages (1) and (2), our goal is to determine if thinning the stand is necessary. At stage (1), we will also account for the site preparation and planting costs associated with the stand. Therefore, we will begin our analysis at stage (1) by using node (10). The states consist of applying thinning treatments at different ages and after this treatment, by using the process, which consist of nine alternative options as the stages explained below:

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1. At stage (1), the following parameters to be determined:

(Stage)	(From-node)	(Net revenue)	To-node	Route
1	1	37017767	3	1- 3

As a result of this analysis, R1 = 37017767 ID. The results show the best path route is from nodes 1 to 3, 5 is to node 10, the clear-cut activity, the best path route from each state, is denoted with (*), here net revenue is used for choosing the best alternatives. What this provides is the cumulative (net revenue) of the path route.

2. We find the following results by moving one stage:

(Stage)	(From-node)	(Net revenue)	To-node	Route
2	3	123593032.6	5	3 – 5 – 10

At this point in the analysis of the net revenue calculations take into account the (net revenue) associated with the decision made at this (stage) as well as the (net revenue) related to the best path route from the (to-node) to the final destination. Specifically, the net revenue that moves from node (3) to node (5), which includes the (net revenue) related to this thinning option and the net revenue at the final harvest, is 160610799.6 ID + 35728550.01 ID at node (10).

And if we are at node 3, proceed to node 5, then to node 10 (20% thin, 20% thin, final harvest). These net revenue calculations are important for evaluating different management alternative options and making informed decisions about the best course of action for maximizing the value of the forest investment.

3. In stage (3) Each of two options includes the cost of site preparation and planting, as well as the discounted cost of thinning options:

(Stage)	(From-node)	(Net revenue)	To-node	Route
3	1	148184897.8	10	1 – 4 – 6 – 10
3	1	146083382	10	1 – 4 – 9 – 10

More details and as a result, the best option for this stand is:

- Site preparation and plantation: This involves the initial cost of preparing the site for planting, followed by planting the seedlings and allowing them to grow to maturity.
- Thinning 20% of the stand at the age of 4 years: This involves removing a portion of the trees in the stand at the age of 4 to promote growth and increase the overall value of the trees.
- Thinning 20% of the stand at the age of 6 years: This involves removing a portion of the trees in the stand at the age of 6 to promote growth and increase the overall value of the trees.
- The final harvest of the stand at the age of 10 years: This involves harvesting the trees in the stand at the age of 10 to obtain the final product.

This management system has been determined by drawing the path route using appropriate values. Specifically, P1 = node (1) refers to moving from site preparation and planting to thinning 20% of the stand at the ages of (4 and 6) and then harvesting at the age of 10, and P2

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= node 1 refers to moving from site preparation and planting to thinning 20% of the stand at age 4, to thinning 20% of the stand at age 9, and then harvesting at age 10.

4. Stage (4), this stage consists of the three- management alternative options as follow:

(Stage)	(From-node)	(Net revenue)	To-node	Route
4	1	160610799.6	10	1- 3 – 5 - 10
4	1	149590071.6	10	1 – 5 – 7 – 10
4	1	139784916.3	10	1- 5 – 8 – 10

For more details about this stage, we explained the process as below:

- Site preparation and plantation.
- Thinning 20% of the stand at the ages of 3 and 5, followed by the final harvest at 10 years.
- Thinning 20% of the stand at the age of 5, followed by thinning 20% of the stand at the age of 7, followed by final harvest at 10 years.

While to determine the best alternative option, the cost of site preparation and plantation, as well as the discounted cost of the thinning options, must be taken into account. And based on this analysis, the option 1 is the best choice in this stage. This decision was determined by drawing the path route using appropriate values.

Specifically, P1 = node (1) refers to the path from site preparation and planting to thinning 20% of the stand at the ages of 3 and 5, followed by the final harvest at 10 years. **Similarly, P2** = node (1) refers to the path from site preparation and planting to thinning 20% of the stand at the age of 5, followed by thinning 20% of the stand at the age of 7, followed by the final harvest at 10 years. **And P3** = node (1) refers to the path from site preparation and planting to thinning 20% of the stand at the age of 5, followed by thinning 20% of the stand at the age of 8, followed by the final harvest at 10 years.

5. Stage (5) refers to the following three-management alternative options, which are available for this stand:

(Stage)	(From-node)	(Net revenue)	To-node	Route
5	1	205309926.1	6	1- 6
5	1	148184897.8	10	1 – 4 – 6 – 10
5	1	126261498.4	10	1- 6 – 8 – 10

In below we can understand the details about this stage:

- Site preparation and plantation, followed by the final harvest at 6 years.
- Site preparation and plantation, followed by thinning 20% at the ages of 4 and 6, and the final harvest at 10 years.
- Site preparation and plantation, followed by thinning 20% at the age of 6, and 8, and the final harvest at 10 years.

To determine the best option, the cost of site preparation and plantation, as well as the

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discounted cost of the thinning options, must be taken into account. Based on this analysis, the alternative option 1 is the best choice in this stage. This decision was determined by drawing the path route using appropriate values. **Specifically, P1** = node (1) refers to the path from site preparation and plantation to thinning 20% at the age of 6, and the final harvest at 10 years. **Similarly, P2** = node (1) refers to the path from site preparation and plantation to thinning 20% at the ages of 4 and 6, and the final harvest at 10 years. **And P3** = node (1) refers to the path from site preparation and plantation to thinning 20% at the ages of 4, 6, and 8, and the final harvest at 10 years.

6. The best alternative option for stage (6) includes the cost of site preparation and planting as well as the discounted cost of thinning options:

(Stage)	(From-node)	(Net revenue)	To-node	Route
6	1	149590071.6	10	1 – 5 – 7 – 10

After analyzing as mentioned above the best alternative option for the stand in this stage is:

Site preparation and plantation, and then thinning 20% of the stand at the ages of 5 and 7, followed by final harvest at 10 years. This decision was determined by drawing the path route using appropriate values. **Specifically, P1** = node (1) refers to the path from site preparation and planting to thinning 20% at the ages of 5 and 7, and the final harvest at 10 years.

7. Stage (7) includes two considered alternative options; which involve the cost of site preparation and planting, along with the discounted cost of thinning options:

(Stage)	(From-node)	(Net revenue)	To-node	Route
7	1	139784916.3	10	1 – 5 – 8 – 10
7	1	126261498.4	10	1- 6 – 8 – 10

As shown above and after evaluating the alternative options, the best alternative that has been determined for this stand is, site preparation and plantation, thinning 20% of the stand at the ages of 5, 6, and 8, and then the final harvest at the age of 10. This decision was made by drawing the path route using appropriate values. **Specifically, P1** = node (1) refers to the path from site preparation and plantation to thinning 20% at the ages of 5 to 8, and the final harvest at 10. **Similarly, P2** = node (1) refers to the path from site preparation and plantation to thinning 20% at the age of 6 to 8, and the final harvest at 10.

8. In this stage, the alternative options include the cost of site preparation and planting, along with the discounted cost of thinning options:

(Stage)	(From-node)	(Net revenue)	To-node	Route
8	1	146083382	10	1 – 4 – 9– 10

In stage (8), after evaluating the best alternative options, has been determined that for this stand is, site preparation and plantation, Thin 20% of the stand at the ages of 4 and 9, and then the final harvest at the age of 10. This decision was made by building the path using appropriate values. **Specifically, P1** = node (1) refers to the path from site preparation and planting to thinning 20% at the ages of 4 to 9, and the final harvest at 10.

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9. Stage (9) consist of 7 options considered including the cost of site preparation and planting, as well as the discounted cost of thinning options:

(Stage)	(From-node)	(Net revenue)	To-node	Route
9	1	187015922.5	10	1- 10
9	1	160610799.6	10	1- 3 – 5 - 10
9	1	148184897.8	10	1 – 4 – 6 – 10
9	1	149590071.6	10	1 – 5 – 7 – 10
9	1	139784916.3	10	1-5 – 8 – 10
9	1	126261498.4	10	1- 6 – 8 – 10
9	1	146083382	10	1- 4 – 9 – 10

In this stage, and based on the results above, it has been determined that, site preparation and plantation, thin 20% of the stand at the ages 3, 4, 5, 6, 7, 8, and 9, then the final harvestat the age of 10. The decision of management system was made by drawing the path route using appropriate values. **Specifically, P1** = node (1) refers to the path from site preparation and planting to thinning 20% at the ages of 3, 4, 5, 6, 7, 8, and 9, and the final harvest at 10. And the following are the details of all path routes (P1,.. P7):

P1 = node (1) refers to the best decision in this stage of management, which is to harvest the stand at the age of 10 without thinning.

P2 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the ages of 3, 5, and then harvest at the age of 10.

P3 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the age of 4, then thin 20% of the stand at the age of 6, and then harvest at the age of 10.

P4 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the age of 5, then thin 20% of the stand at the age of 7, and then harvest at the age of 10.

P5 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the age of 5, then thin 20% of the stand at the age of 8, and then harvest at the age of 10.

P6 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the age of 6, then thin 20% of the stand at the age of 8, and then harvest at the age of 10.

P7 = node (1) refers to the best decision in this stage of management, which is too thin by 20% of the stand at the age of 4, then thin 20% of the stand at the age of 9, and then harvest at the age of 10.

While considering all the recursion routes for calculating net revenue, the results show that the path route from node 1 to node 10 is denoted by (*), as a suggested alternative option, and there is also suggested option of the route from node 1 to node 6, which is the best final harvesting activity. The net revenue results show two possible routes: one from node 1 to node 10, and

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another from node 1 to node 6, which determines the highest revenue at age 6 years. This finding is consistent with previous studies in the field of determining the optimum economic rotation age for poplar stands in northern Iraq and other places. For example, Shareef (2002), Al-Sarraf (2007), Shayma (2011), and Niemczyk *et al.* (2016) found that higher biomass productivity is achieved over an initial 6-year cycle than over a 5-year one. Oliveira et al. (2020) suggested that rotations of 2 to 4 years have been the most frequently employed for poplar short rotation coppice plantations. Ghezehei *et al.* (2020) found that the optimal rotation age may be up to 10 years in a study conducted in South Carolina, USA. Heshmatol et al. (2020) also found that the rotation age of 10 years was the most economically optimal for high-yielding black poplar clones. Finally, study by Ghezehei *et al.* (2021) aimed to determine the revenues from stands in 12-year rotations

Table 5: Shows the Net Revenue of all the options of (8) path routes, including nod-to-nodes

Net Revenue	Route
187015922.5	1-10*
205309926.1	1- 6*
160610799.6	3 - 5 -10*
148184897.8	4 - 6 -10
149590071.6	5 -7 – 10
139784916.3	5 - 8 – 10
126261498.4	6 – 8 – 10
146083382	4 - 9 – 10

CONCLUSIONS

The analytical approach of Dynamic Programming was used in this study to determine the optimal harvest age for a Poplar stand in the Zakho forest.

- The results showed that Poplar stands in the Zakho forest are a profitable investment, providing economic returns in a relatively short period of time due to their stand properties and characteristics in the study area.
- It was concluded that there is no need to establish artificial stands for the final harvest at the end of a rotation age, as continuous monitoring of the demand for timber in the market and harvesting operations before reaching the rotation age can be a viable option. Thinning treatments may be necessary to recover a portion of the capital invested in the stands. Waiting for a rotation period of 10 years may not be feasible from an economic perspective, as it may result in a long period without returns.
- This study found that without thinning, the best decision for harvesting was at age 6, but with thinning, the best two options were the routes of 1-3-5-10 and 1-5-7-10. The use of advanced programs that employ quantitative approaches in forest planning and decision-making can be beneficial in addressing problems that may have significant negative impacts on investments in forestry projects.

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The use of advanced programs, particularly those that employ quantitative methods, can be highly beneficial in the development of decision plans for forest utilization and addressing issues that may have a significant impact on investments in forestry projects.

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