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Charles W. Smart
Virginia Polytechnic Institute and State University

Edward B. Rayburn
Virginia Polytechnic Institute and State University

Oscar T. Sanders
Virginia Polytechnic Institute and State University

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$$TC = 5(F) + 15,881 (V)$$

if $F = \$100.00$ and $V = 1.00$, then

$$TC = 500.00 + 15,881 = \$16,381$$

The total weekend kill $(P \cdot m)$ is $(4517 \cdot 3.0) = 13,551$ quail.

This example demonstrates the use of the model, resulting in a calculation of 4,517 hunter days of quail-based recreation being produced for a minimum total cost of $16,381, or about $3.60 per hunter day.

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FORMULATION OF AN OPTIMUM WINTER FOOD-PATCH MIX FOR BOBWHITE QUAIL

Charles W. Smart, Edward B. Rayburn, Oscar T. Sanders, Division of Forestry and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg

Abstract:

Many state game agencies are seeking to improve winter quail food and habitat by means of artificial food-patch plantings. The objective of such plantings is to increase the limited supplies of nutrients available to quail in late winter. Desirable qualities of food species included in the seeding mixture are: low seeding cost, high nutrient and energy content, persistent seeds, and cultivation ease.

Presently used mixtures have been formulated in the absence of detailed nutritional analysis and cost-minimization techniques. This paper seeks to demonstrate the utility of modern operations-research technology in such decisions by outlining the procedures for determining the composition of an optimum food-patch mix. This mix will meet nutrient and cultivation requirements at a least-possible cost per acre of food planting. Although a solution is presented, the emphasis of the paper is on the method for obtaining such a solution.

In many states, the establishment of artificial food-patch plantings is a major activity in bobwhite quail management programs. The

purpose of these plantings is to increase the quantities of vegetable foods available to quail during the winter when adequate food supplies are critical to survival. Much study has been devoted to the formulation of seed mixtures to be used for constructing these food plantings. The literature abounds with quail food-preference studies for various regions of the country (2,5,10). A number of authors make recommendations for seed mixtures suitable for bobwhite food patches under a variety of conditions (8,9,13).

Artificial food patches, however, are expensive to establish and maintain. Seed procurement and planting costs may be high, especially for nonagricultural plant species. Nutrient content also varies between different quail foods. The mixtures that have previously been proposed were formulated largely on the basis of food-preference data. Little explicit thought was given to the balance of nutrients in the diet or to minimizing the cost of food plantings. Nutritional data concerning both quail requirements and the chemical composition of seeds were minimal. Techniques for cost minimization were, as yet, undeveloped.

In recent years these gaps in knowledge have been narrowed. Minimum dietary requirements have been determined for poultry and some quail species. Biochemical analysis has established the occurrence of nutrients in many grains. Workers in the field of operations research have developed a number of powerful mathematical techniques which, when combined with modern computer capabilities, allow administrators to quickly determine least cost and maximum benefit management alternatives (11,12).

The availability of nutritional data and optimization methods offers an opportunity to rethink and improve the formulation of quail food-patch mixes. This paper seeks to demonstrate the use of linear programming in developing an optimum planting mixture. The food species considered in the following example were selected for use under the climatic conditions of Virginia. In other states, some species would be deleted from consideration while others might be added. The methodology however, is identical for any region, no matter what food plants are included in the analysis.

The authors gratefully acknowledge Dr. Robert H. Giles, Jr., Associate Professor of Wildlife Management, and Mr. Glenn R. Dudderar, Wildlife Extension Specialist, for their aid in compiling data and reviewing the manuscript.

Example Problem

It is desired to establish a series of artificial food patches for bobwhite quail throughout Virginia. The principal objective of the program is to increase the limited supplies of energy and nutrients available to quail in late winter (February), when food appears to be a limiting factor. The manager wishes to determine the seed mix that will provide the maximum metabolizable energy per planting dollar expended. At the same time he would like to provide a balanced diet of protein, calcium, phosphorus, lysine, and sulfur amino acid.

The species selected by the manager for possible inclusion in a planting mixture for Virginia are listed in Table 1. The criteria for the selection of any species are threefold. First, the species must be able to germinate and reach maturity under the climatic and soil conditions of Virginia. Secondly, it must require little or no intensive cultivation. Seedbed preparation may be undertaken, but no other care should be required. Thirdly, the seeds must be persistent and available to quail in February and later months. All 3 are qualitative judgements which must be made by the manager on the basis of his past experience and the advice of agricultural experts.

Table 2 summarizes the nutrient requirements of quail. These are the minimum values which the manager must seek to meet in his food plantings.

Methods

The seed mixture problem may be formulated as a linear programming problem in the following manner.

For each species (i) a coefficient (C_i) representing energy production per dollar expenditure may be determined. Column 1 (energy production) and Column 2 (yield) from Table 1 are multiplied together and the product is divided by the entry in Column 3 (cost). For example, the coefficient for corn is:

$$3400 \times 1900 / 45 = 143555.50$$

If this coefficent is multiplied by a value, x_i, representing the proportion of the seed mixture allocated to species i, the product may be thought of as the proportional contribution of that species to the overall energy/cost ratio of the mixture. The manager's objective is to find the mixture of seed that will make this overall ratio as large as possible, while satisfying other minimum nutrient requirements. These nutrient requirements may be included in the problem as constraints. For each nutrient (j) and plant species (i) a percentage (a_{ij}) may be read from the appropriate column in Table 1. The protein content of corn is, for example, 8.70%. If M_j (as recorded in Table 2) is used to designate the minimum quail requirement for nutrient j, the amount by which seed production by plant species i surpasses this nutrient requirement is given by the expression:

$$P_i (a_{ij} - M_j) x_i$$

where P_i = the potential yield of species i (Column 2, Table 1).

The result may be negative for species with low nutrient contents.

The problem may be summarized for n food species in mathematical notation. The manager's goal is to maximize the overall energy production to cost ratio:

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$$\text{Max } X_o = \sum_{i=1}^{n} C_i x_i \tag{A}$$

However this maximization is subject to a number of constraints:

$$\sum_{i=1}^{n} P_i (a_{ij} - M_j) x_i \geq 0; \text{ for all } j \tag{B}$$

One such constraint must be applied for each nutrient of interest.

The maximization procedure is subject to only 2 other types of constraints. The sum of the proportions in the final mixture must equal 1:

$$\sum_{i=1}^{n} x_i = 1.00 \tag{C}$$

Also each individual x_i must be greater than or equal to zero:

$$x_i \geq 0; \text{ for all } i \tag{D}$$

Obviously no species can compose a negative proportion of the mixture.

Once the problem has been reduced to the form of equations (A) through (D) it may be solved by any 1 of a number of linear programming algorithms adapted to digital computers. The problem presented here was solved with the IBM-supplied mathematical programming system, MPS/360. Initial coefficient calculating and card punching was performed in a FORTRAN IV program written by the senior author.

Results and Discussion

The linear programming solution to the sample problem indicated that 2 species should be included in the planting mixture. Their relative proportions, by weight, should be: sunflower (0.77) and kafir sorghum (0.23). The proportion of all other species in the mix should be 0.00. Multiplying each proportion by the standard seeding rate for that species (Table 1, Column 4), and summing the 2 products indicated that this mixture should be applied at a rate of 24 pounds per acre.

This, then, is the seed mixture which best achieves the manager's stated objectives. It attains the greatest possible energy-production-to-cost ratio while satisfying the constraints set by equations (B) through (D).

However the manager must still exercise some judgement before adopting such a mixture. Energy and nutrient requirements are satisfied, but a number of other considerations are important. The manager must make sure that the selected plant species are relatively familiar to quail. Stoddard (10:125) stated that quail may require 2 or 3 seasons before they will accept a new food. This type of consideration should be applied when initially establishing the list of species suitable for food plantings. In addition the manager must remember that not

Table 1. Nutritional and agronomic characteristics of selected quail food plants.*

Species name	Metab. energy (Kcal/Kg.)	Yield (Kg/acre)	Planting cost ($/acre)	Seeding rate (lbs/acre)	Crude protein (%)	Calcium (%)	Phosphorus (%)	Lysine (%)	Sulfur amino acid (%)
Corn	3400.00	1900.00	45	16.0	8.70	0.04	0.31	0.27	0.34
Serecia Lespedeza	2200.00	91.00	12	15.0	34.70	0.15	0.40	0.15	0.30
Common Lespedeza	2200.00	91.00	12	15.0	40.60	0.15	0.40	0.15	0.30
Lupine	2200.00	91.00	40	28.0	39.20	0.05	0.40	0.10	0.30
Foxtail Millet	2200.00	91.00	20	40.0	12.10	0.05	0.28	0.30	0.13
Japanese Millet	1500.00	91.00	20	40.0	12.00	0.05	0.28	0.30	0.13
Wild Oats	2600.00	400.00	30	64.0	11.70	0.11	0.35	0.36	0.36
Cow Pea	3328.00	220.00	35	90.0	23.40	0.17	0.50	0.15	0.30
Winter Pea	2601.00	136.00	35	60.00	22.50	0.17	0.50	0.15	0.30
Canadian Pea	2600.00	136.00	35	90.00	22.50	0.17	0.50	0.15	0.30
Partridge Pea	2000.00	140.00	35	60.0	36.30	0.17	0.50	0.15	0.30
Broom Sorghum	3400.00	1800.00	25	5.6	9.70	0.03	0.35	0.18	0.09
Grain Sorghum	3500.00	1800.00	25	5.6	11.10	0.04	0.31	0.27	0.45
Hegar Sorghum	3500.00	1800.00	25	5.6	10.00	0.04	0.33	0.18	0.20
Kafir Sorghum	3500.00	1800.00	25	5.6	11.80	0.04	0.33	0.27	0.20
Milo Sorghum	3250.00	1800.00	25	5.6	11.00	0.04	0.29	0.27	0.34
Sorgo Sorghum	3000.00	1800.00	25	5.6	9.60	0.04	0.30	0.25	0.25
Soybean	2500.00	410.00	35	30.0	37.90	0.25	0.59	2.40	1.05
Sunflower	2500.00	1000.00	20	30.0	41.00	0.43	1.04	2.00	1.60

*From Anonymous (1966), Crampton and Harris (1969), and Hubbell (1971).

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all of the additional nutrients will be available to quail. Other
wildlife species in competition for the same food supply may significantly
reduce the effectiveness of any planting program.

After determining an optimum mixture, the manager must make certain
that the species to be planted are not potential competitors. Linear
programming provides no means of allowing for detrimental interactions;
these must be recognized by the manager. One solution to potential
competition problems would be strip planting of the individual species,
instead of completely random seed dispersal. The manager must also be
certain that his mixture is sufficiently diverse to insure success
over the range of site conditions on which he must plant (8,13). If
it is not, then he should compile separate species lists and redo the
analysis for each set of environmental characteristics which he is
likely to encounter. Without such analyses the failure of food plants
to become established on adverse sites may completely outweigh the value
of the entire cost minimization-energy maximization procedure.

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      techniques. The Wildl. Soc., Washington, D. C. 623 p.

Table 2. Minimum nutritional requirements of quail.*

Nutrient	Percent of diet
Crude protein	24.00
Calcium	0.44**
Phosphorus	0.65
Lysine	1.40
Sulfur amino acids	0.80

* From National Academy of Sciences (1971). Values are for coturnix
quail.

**From Miller (1967). A value of 0.20 was used in the actual analysis
since it was apparent that no combination of species could meet the
requirement of 0.44 percent.

SUMMATION OF THE NATIONAL BOBWHITE SYMPOSIUM

E. V. Komarek, Tall Timbers Research Station, Tallahassee, Florida

Your chairman, Dr. Morrison, has given me a difficult task indeed.
That is to present to you a summation of this National Bobwhite
symposium which in truth is within itself a summation of a large amount
of investigative effort and study. No one person could absorb all of
this information in a few days, and it would be presumptuous for me to
try to do so. Perhaps I may be permitted to bring to you, then, what
might be called the "sense of the meeting." Certainly this Symposium
reflects the state of the science and art of bobwhite quail research
and management including the many ramifications so necessary due to
variations in the bird's habitat requirements throughout its wide range.

As was most fitting, the meeting had a prologue in a bird dog
demonstration and workshop: without the use of bird dogs the hunting
of the bobwhite would lose its attraction to many of its devotees. The
use of dogs in bobwhite hunting brings in many extra problems, as the
environment must be so managed not only to produce the quail, but to
produce conditions in which bird dogs can operate well and be