AN ABSTRACT OF THE THESIS OF

Marc G. Vomocil for the degree of Master of Science
in Forest Management presented on June 8, 1981
Title: Effects of Different Yield Functions and Initial Inventories on Harvest Schedules for Douglas-fir
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The procedure of forest level harvest scheduling incorporates many inputs of an uncertain nature. Forest management planners must be aware of the possible effects of the use of erroneous input information on the results of their planning. With that knowledge they can better plan a risk management strategy and make appropriate adjustments in assumptions or recommendations.

Two of the most important uncertain input elements are future yield predictions and initial inventory information. The objective of this study was to identify the size of effects on harvest schedules of using uncertain yield and inventory data, specifically for Douglas-fir of the Pacific Northwest. To do this sensitivity analysis, harvest schedules were developed using the sequential even-flow option of the TREES simulation model (Tedder et al. 1980) with a ceteris paribus format where all was held constant except the yield predictions or the initial inventory data.

Several different yield models have been developed for predicting future yields of Douglas-fir. For extensive management, this study compares four plus an arbitrary adjustment of one of the four in a harvest scheduling context; hypothesizing that there should not be any meaningful differences in harvest schedules developed when using the different yields. The tested yields included Bulletin 201 (McArdle et al. 1930), DFIT (Bruce et al. 1977, Reukema, Bruce 1977), DNR Empirical Yields (Chambers, Wilson 1972), Hoyer's Natural Stand Yields (Hoyer 1975), and Bulletin 201 less 15 percent. Bulletin 201 as modified by Beuter et al. (1976), DFIT, and modified Bulletin 201 less 15 percent were tested for intensive management.

Eight sample inventories were obtained that represent a spectrum of site class and initial structure. Each inventory is adjusted twice to make a total of 24 different inventories which are combined with the yield information to generate the harvest schedules. Relative differences in percent are reported with emphasis on first decade, last decade, and total planning horizon differences.

Effects of Different Yield Functions and Initial Inventory on Harvest Schedules for Douglas-fir

by

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A THESIS

submitted to

Oregon State University

in partial fullfillment of
the requirements for the
degree of

Master of Science

June 1982

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Acknowledgement

I gratefully ackowledge the encouragement and assistance of my major professor, Dr. Philip L. Tedder and my parents, Dr. and Mrs. James A. Vomocil. I warmly thank the other forestry graduate students whose support and friendship made this project worthwhile. Most of all, I thank Sally for her assistance, encouragement, and patient endurance.

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EFFECTS OF DIFFERENT YIELD FUNCTIONS AND INITIAL INVENTORIES ON HARVEST SCHEDULES FOR DOUGLAS-FIR

I. INTRODUCTION

Harvest scheduling is the process used in forest management planning to establish short-run harvest levels and make projections of long-run harvest levels and the resulting age-class distribution of the forest. It is done to ascertain the availability of future timber harvests. Ware and Clutter (1971) emphasize the importance of the harvest schedule by noting it controls growing stock volumes over time, growth rates, cash flows, the present net worth of the forest, and returns on investment made in the forest.

Historically, harvest scheduling has been an important part of the strategic planning process. It will become an even more important part as the demand for forest products increases and supply decreases, resulting in higher values for the timber resource. As the timber resource becomes more valuable, it becomes more important that forest management planners have a thorough understanding of harvest scheduling and the effects that changes in data have on the resulting harvest schedule.

Harvest scheduling is sensitive to many key items, most of an uncertain nature. Some of the more important are the growth and yield information, regular and catastrophic mortality, initial inventory, expected silvicultural activities and the level of implementation of them, anticipated levels of successes and failures of those activities, future utilization standards, anticipated changes in the land base, environmental constraints, the inherent productive capacity of the forest, and changes, positive or negative, in it (Davis 1966, OSFD 1979).

The objective of this study is to determine the sensitivity of short-run and long-run harvest levels to changes in two of those key elements: future growth and yield assumptions, specifically for Douglas-fir, *Pseudotsuga menziesii*, of western Oregon; and initial inventory data.

Harvest schedules are affected by future yield expectations and initial inventory but both these inputs are subject to substantial uncertainty. Forest managers must be aware of the effect on their planning of input data that is subject to uncertainty. Identifying relative differences in harvest schedules under varying assumptions should help planners better establish potential gains or losses facing them when they use uncertain inputs. Recognition of these potential gains or losses can be used when assumption strategies are being formulated (Fight, Bell, 1977) or required precision levels are being set (Hamilton 1970, 1979).

One purpose of harvest scheduling is to plan harvest levels for a forest over time, called the allowable cut, so that the owner's objectives are best achieved. Marty (1975) suggests three minimum objectives that are important to achieve. First, the harvest schedule should insure a minimum level of harvest consistent with the initial inventory and long-term productivity of the forest under conservative management intensities. Second, progress should be made towards a balanced age-class distribution, i.e., towards a regulated forest. Third, the harvest schedule should result in a minimum return on investment for each silvicultural treatment undertaken and maintain a minimum rate of value growth in all age classes.

There are two parts of the plan that is developed to allocate harvests over time to accomplish those objectives. The first part is the short-term harvest which is to be implemented in the field; that is when to cut, how much, and where. This can include the cut up through the first decade.

The second part is the long-term projection which includes cut levels beyond the first decade through the end of the planning horizon and projections of the condition of the resource base that results from its use through time. The planning horizon is the time period being analyzed in the harvest scheduling process. If it is long enough to permit the equilibrium condition of a regulated forest to be established where annual harvest is equal to annual growth in perpetuity then the harvest level is called the long-run sustained yield. The long-run sustained yield depends on the inherent productive capacity of the forest adjusted for anticipated management intensity.

Long-term projections are not actually implemented although they are an estimate of the future based on the best information available at the time. As Beuter et al. (1976) noted,

> "The projections are not intended to be forecasts of what will happen; they should not be interpreted as such. A projection simply indicates what would happen if its assumed set of conditions did indeed occur."

Frequent revision of harvest plans of at least once every ten years is the reason harvest levels computed for beyond the first few years are not implemented in the field.

Another main use for harvest scheduling, which utilizes long-term projections, is in timber supply studies (U.S.D.A. 1974, Gedney et al. 1975, Beuter et al. 1976, Hatch et al. 1976). These studies are done on behalf of the public so that policy makers will have information about possible outcomes of alternative management policies on future supplies of timber in a specific geographic location.

Harvest scheduling is an old concept in forest management, dating from early German forestry. Davis (1966) describes several of the traditional methods and formulas that have been used to calculate harvest levels. The three main types of traditional methods are area control, in which an equal area is cut each year (or period); volume control, in which an equal volume is cut each year; and area-volume check; where an equal volume is planned for each year with a subsequent check on the projected age-class distribution of the forest to see that it meets certain management constraints.

Until recently, these methods involved long and tedious hand calculations. Within the last 15 years, however, several complex, flexible computer programs have been developed to do harvest scheduling computations. Examples include SIMAC (Sassaman et al. 1972), SORAC (Chappelle, Sassaman 1968), Timber RAM (Navon 1971), and TREES (Tedder et al. 1980). While these tools remove the drudgery of doing hand calculations, they are, for the most part, computerized versions of traditional methods, i.e., making a cut from current inventory resulting in a change in the age-class distribution, updating the inventory via growth and yield information to the next time period, making another cut, and so on.

The main benefit of these programs is that they permit rapid testing of a wide range of different assumptions concerning the data base and future events. Because these models are complex,effects on current harvest levels from changes in such things as future management intensity assumptions are unpredictable without substantial testing (Marty 1975). The present study uses sensitivity analysis to address what if questions concerning effects of yield information and initial inventory accuracy on calculated harvest schedules.

Several different models are being used in the Pacific Northwest to predict future yields per acre of Douglas-fir stands. The hypothesis to be tested is there should not be any significant differences in short-term or long-term harvest schedules developed in a ceteris paribus format using different yield predictors. This study could be viewed as a comparison of different Douglas-fir yield models in a harvest scheduling context, i.e., comparing results of the use of model predictions rather than the predictions themselves. To make these comparisons harvest schedules are developed using the Timber Resource Economic Estimation System simulation model, TREES (Tedder et al. 1980). All assumptions and input items are held constant between simulations except the yield information so that any resulting differences in harvest schedules reflect yield model differences. The same ceteris paribus technique is used to test for effects of using inventory data that doesn't correctly reflect the true forest condition. A worst-possible-case inventory error is simulated so that any harvest level differences which result will establish ranges for inventory error effects.

The literature review chapter discusses how results from the present study could be utilized as input into analysis techniques developed by others, elaborates on the importance and uncertainty of yield and inventory input, and reviews other studies which used sensitivity analysis in a forestry framework. The methods section describes the yield models that are being compared, how yields used in the present study were generated, and what these yields are. Intensive management yields and approach to normality figures are developed and the base inventories and adjustments to them are described. Simulation comparison sets are established and basic assumptions common to those sets are shown. The results chapter identifies percent harvest level differences between comparison pairs for first decade levels, last decade levels, total harvests over the planning horizon, and on a period by period basis. The conclusions section discusses the significance of the results to forest management planners, identifies short-comings of the present study, and suggests further work on the topic.

II. LITERATURE REVIEW

Uncertainty in timber harvest planning has often been ignored in the past with only point estimates being reported in harvest plan recommendations, public policy studies, and timber supply studies. It is important that such results be viewed as representative of ranges and not as exact or fixed. The capability of testing assumptions about the data base permitted by computer programs allows for more explicit consideration of uncertainty in harvest scheduling.

Recent work by Hamilton (1970, 1979) and Fight and Bell (1977) examine techniques to identify implications of forest management planning under uncertainty. If perfect knowledge was available then an optimal harvest plan could be generated. Any deviation from this plan requiring an adjustment in the cutting schedule due to imperfect knowledge is considered a loss (Fight, Bell 1977). For example, an overestimate of future growth, utilization, or of initial inventory volumes per acre causes harvest levels higher than would be planned if perfect data was available. Downward adjustments would have to be made in future harvests resulting in economic disruptions. This overcutting can result in an undesirable, unbalanced age-class distribution. On the other hand, if an underestimate is made of the input items mentioned then an undercut relative to what could have been harvested will be planned. The loss would be missed opportunities.

Relative differences in harvest schedules generated using different input data as is done in the present study can serve as the loss. This information could be used in developing loss functions for setting precision levels when designing inventories (Hamilton 1970, 1979). It could also be used in a less formal analysis by resource planners to decide if there is a need to intensify data collection (Gedney 1979, Fight, Bell, 1977). After identifying potential losses,assumptions are chosen for use in planning which will minimize chances of the occurrence of an adjustment having the most adverse consequences. Ware and Clutter (1971) describe the goal of this effort as the development of harvest plans relatively stable over a range of input of an uncertain nature. Hamilton (1970, 1979) describes it as the least-cost-plus-loss approach where cost refers to the cost of improving the certainty of the input base, e.g., more intensive sampling.

Yield information, whether in table or equation form, predicts the amount of wood to be found on an acre given stand age, productive capacity of the area, called site class, and stand history (Curtis 1972). Future yield expectations are dependent on inherent biological potential, mortality, expected silviculture activities, and future utilization and recovery standards. These factors, plus wide variation inherent in biological systems and lack of long-term yield study conclusions, results in uncertainty in yield predictions (Bruce et al. 1977).

Yield per acre for a given age class times the number of acres in that age class from the inventory gives total volume available for harvest from that age class. This summed over all merchantable age classes is the total growing stock volume available for harvest at the time of the inventory. It is easy to see why future yield expectations play such an important role in harvest scheduling. This is especially true when short-term harvest levels are affected by projected future harvest levels, such as when an even-flow of volume or sequential even-flow of volume technique is used (Bell 1976).

As indicated, merchantable yield per acre for an age class times the number of acres in that age class summed over all age classes is the volume available for harvest. Initial volumes per acre and number of acres are obtained from inventory information. It follows that inventory information affects the computed harvest levels, not only in the short-run but also until equilibrium is reached and the long-run sustained yield harvest level is achieved.

The nature of the resource dictates that forest inventory information be gathered using sampling, quite often of an extensive nature resulting in uncertainty about the accuracy of forest inventory data. Two recent studies in Oregon that use harvest scheduling techniques, one for operations planning (Oregon State Forestry Department 1979) and the other for timber supply projections (Beuter et al. 1976), noted the weakness of the inventory component.

Sensitivity analysis is often used to address stand level and forest level questions because of the long time frames involved in field testing in forestry. Descriptions of several examples of the use of sensitivity analysis follow.

Output from stand level projection models can be used as expected yield inputs in a forest level harvest scheduling model. Frayer and Jones (1970) examined the effects of estimated input data on output for a stand level model of Vermont softwoods. By making multiple runs, varying input items according to the distributions of the samples used to generate inputs, a distribution of outputs was generated. This helps to show that output from such models are not fixed point estimates but are, in fact, means of distributions. Carrying this approach to forest level models, yield inputs used are just point estimates of means of distribution. The same could be said of other input items. If input distributions were used in a forest level model an output distribution could be generated instead of the point estimates which are usually made.

Two other examples of sensitivity analysis applied to stand level situations are studies by Goforth and Mills (1975) and Schweitzer (1968). In designing a computer program to analyze forest investment opportunities Goforth and Mills acknowledged that input data must be entered with some degree of uncertainty. The level of uncertainty can be reduced but only at a cost of time and money. Their program determines if data changes within the established uncertainty level would have any significant effect on results. It does this by computing the percent change that would have to occur in a data item before the computed result would differ from the base by more than a pre-set error threshold. Schweitzer developed a similar computer program to analyze potential forest investments. His program generates distributions of present net worths, using point and probabilistic estimates of costs, prices, and yields.

The Forest Service has conducted studies that used sensitivity analysis to address forest level harvest scheduling questions. Four examples which should be noted are Bell (1976), Sassaman and Schallau (1970), U.S.D.A. (1976), and Fight and Schweitzer (1974).

Bell (1976) examined the effects of increased stand yields resulting from a change in silvicultural treatment on forest level harvest schedules. He used Timber RAM (Navon 1971) as the computational tool and non-declining even flow as the harvest policy. This policy maximized first decade harvest subject to a constraint that harvest not be permitted to decrease during the planning horizon. Linking period harvests like that results in future period harvest levels affecting the first period harvest level, and all harvest periods as well. A change in short-term harvest levels resulting from some change that affects future yields and harvest levels is known as the allowable cut effect (Schweitzer et al. 1972). Bell (1976) showed that, contrary to traditional thinking, it is possible for activities that increase future yields (such as fertilization, in this case) to decrease the computed harvest level, i.e., a negative allowable cut effect. This happened on over half the situations tested but no evidence was observed that might permit predicting such a result.

Sassaman and Schallau (1970) examined the sensitivity of the long-run sustained yield level to the log measurement unit used (Scribner board feet vs. cubic feet), increased management intensity resulting in one-third more yield in the first rotation after a regulated forest is established, and shortening the length of time required for converting to a regulated forest and then maintaining shorter future rotation lengths (60 years vs. 90 to 100 years). The sample inventory used in this study contained a substantial amount of old-growth timber so the expected change in harvest levels is a decrease. The decrease is less with the cubic foot log rule, intensified management, and a longer conversion period and future rotations.

In 1976, the U.S.D.A. published the Timber Harvest Scheduling Issues Study. This exhaustive study examined the current non-declining even-flow method of planning harvests from National Forests and potential alternatives to that. Alternatives included an economic maximization approach, a sequential even-flow approach where harvest levels could change each period either up or down within pre-set bounds, a fixed percent harvest each period, and others. In addition to examining the sensitivity of harvest levels to the computation method, this study examined effects of using different assumptions about future utilization standards, future management intensities, and combining planning areas. The report included an exhaustive examination of concepts of harvest scheduling.

The Timber Harvest Scheduling Issues Study was most similar to the present study in comparisons of harvest schedules for high vs. low management intensities. High management intensity harvest levels for the first decade were 25 percent to 30 percent higher than those projected using less intensive management. Higher levels persisted through the planning horizon. These first decade results, which occurred using several different methods, are another demonstration of the allowable cut effect. The rise in harvests from increased management intensity is a function of the yield assumptions which are made.

No attempt was made in this U.S.D.A. (1976) study to verify the correctness of the assumed yields. Citing from this study,

> "Harvest levels are greatly influenced by the yield assumptions. Because the possible gain is quite large,the error introduced if the yield assumptions are incorrect is a source of concern."

Fight and Schweitzer (1974) used SIMAC (Sassaman et al. 1972) to examine the sensitivity of even-flow allowable cut levels to long-term yield assumptions and to the size and age-class distribution of the initial inventory. While noting the quantitative results are unique to the sample inventories and assumptions involved in the testing, it is suggested the general trends apply whenever a scheduling method is used that constrains a periodic harvest level to that in other periods. Their results can be summarized as follows: 1) Harvest levels are relatively more affected by increases in future yield expectations when the initial inventory is large and evenly distributed across age classes and when growth increases can be harvested relatively quickly from effected stands; 2) Harvest levels are relatively more affected by a change in initial inventory or short-term growth when the initial inventory is small with an irregular age-class distribution.

The first result is another example of the allowable cut effect. A large, well distributed inventory permits more flexibility in taking advantage of long-term growth improvements. Future yield increases can be incorporated into cut levels immediately rather than waiting for them to actually culminate only if there is sufficient mature timber to supply harvest volumes. The second result is intuitively reasonable. If the limiting factor in determining a harvest level is a small or poorly distributed inventory any action that affects that constraint either way will have a substantial effect.

The Department of Natural Resources of the State of Washington has done extensive sensitivity testing of harvest schedules for their Sustainable Harvest Analysis Planning (Chambers, Pierson 1973, Chambers, Summerfield 1975, Chambers 1977a). This planning effort sets and allocates annual harvest levels on lands for which the state has management responsibility. Testing was done using either a linear programming technique or a simulation model with an even-flow method as the harvest scheduling method. Testing has been done to show the sensitivity of even-flow harvest schedules to site quality assumptions (Chambers, Pierson

1973), adding or deleting acres from the forest base (Chambers, Pierson 1973), using combined vs. individual units in the allowable cut base (Chambers, Summerfield 1975), incorporating thinning or other activities into the management regime (Chambers, Pierson 1973, Chambers, 1977b), rotation lengths and lengths of the conversion period (Chambers 1977c), and the rate of rehabilitation of brushland to conifer production (Chambers 1980). In addition, the Department of Natural Resources has examined the sensitivity of the present net worth of their forest resource to many of these same factors and to the assumptions about real price changes for timber (Chambers, Pierson 1973, Chambers 1977c).

Timber supply projections have also used sensitivity analysis. Hatch et al. (1976), in a timber supply study for Idaho, used two different utilization standards and four alternative growth and mortality rates. Results showed that increases in timber supply through improved management were small relative to gains due to relaxed multiple use or environmental constraints.

Timber for Oregon's Tomorrow (Beuter et al. 1976) is another major timber supply study that used sensitivity analysis. Simulation was used to make projections of future timber harvests in Oregon under various assumptions of public and private management intensity and harvest policies. Results show that under current policies and management levels Oregon faces a significant decline in harvest levels over the next 30 years, by 22 percent in western Oregon by the year 2000. These results served as the basis for the Forestry Program for Oregon (Oregon State Forestry Department 1977), a plan put forth by the Oregon State Board of Forestry to coordinate and intensify management efforts on all state and private forests.

Timber for Oregon's Tomorrow results showed that such management intensity efforts have little effect on the decreased timber supply of the next 30 years. It is suggested that only a change in harvest policies can make a substantial difference in preventing the decline; away from non-declining even-flow for public owners and away from 'other objective forestry' for non-industrial private owners. As in the Timber Harvest Scheduling Issues Study (U.S.D.A. 1976), this study (Beuter et al. 1976) assumed the correctness of the yield information used. The authors were explicitly aware of uncertainty in yields and other assumptions and, accordingly, built a flexible simulation model, the Timber Resource Economic Estimation System, TREES (Tedder et al. 1980).

The Forestry Program for Oregon, Phase 1 (O.S.F.D. 1977), which used the Timber for Oregon's Tomorrow results as its base, also noted uncertainty in some of the data base and assumptions. Tests were conducted on the assumptions, data base, and structure of the computer model TREES. Detailed results of these tests were not reported but the following quote summarizes,

> "We tested the O.S.U. (Beuter et al. 1976) growth projections and starting inventory against other sources. Because of the nature of the assumptions and the structure of the O.S.U. model (TREES) direct comparison with other sources of growth data was difficult. Of those comparisons made, analysis indicates the O.S.U. projected yields are conservative for western timbersheds and optimistic for eastern timbersheds. Exact comparison cannot be made between O.S.U. growth equations and the tabular yields used by the U.S.F.S and others" (O.S.F.D. 1977).

The present study attempts to make those comparisons for Douglas-fir via a harvest scheduling sensitivity analysis. In addition, the present study examines the significance of initial inventory errors. While the previous studies examined the sensitivity of harvest schedules to many elements, the significance of these two elements has not been explicitly considered.

III. METHODS

The major steps in this study can be summarized as follows:

1. Obtain, standardize, and formulate the yield predictions to be compared.

2. Obtain appropriate sample inventories and adjust them to approximate initial inventory errors.

3. Establish combinations to be compared.

4. Establish assumptions needed in the harvest scheduling model, build control files, and make simulation runs.

5. Compare harvest levels of appropriate combinations.

Initial plans for this study called for extensive and intensive management regimes. Due to unavailability or incompatibility of several of the yields the initial plan could not be fully achieved. The following yield predictors were available and are used in comparisons:

1. McArdle et al. (1930), commonly known as Bulletin 201, for extensive management and as modified by Beuter et al. (1976) for intensive management.

2. Bruce et al. (1977), Reukema, Bruce (1977), commonly known as Douglas-fir Interim Tables (DFIT), for extensive and intensive management.

3. Chambers, Wilson (1972), commonly known as the DNR Empirical Yield Tables, for extensive management only.

4. Hoyer (1975), commonly known as Hoyer's Natural Stand Yields, for extensive management only.

5. Bulletin 201 (McArdle et al. 1930) less 15 percent for extensive management and as modified by Beuter et al. (1976) less 15 percent for intensive management.

A reviewer (Gedney 1979) of the project proposal anticipated the problem of incompatibility of yield predictors and recommended a different approach. His suggestion was to vary a base yield predictor. This was done to generate the yield set listed fifth.

A 15 percent reduction in yields, or falldown, was selected for this comparison study because it was thought to be the most likely direction and magnitude of errors in future yield predictions. Experience has shown that yields obtained on research plots are never achieved on forest areas overall (Bruce 1977). Reasons for this falldown include unstocked areas such as roads, rock outcroppings, and brush spots, quality control differences between activities on research plots and operational methods, hardwood competition not found in pure species plots, and other unaccounted losses such as insect damage or incomplete utilization.

Bruce (1977) suggests there isn't a single figure that represents the falldown. Meyer (1930), however, estimated that about ten percent of an average Northwest stand is unstocked area and that yields of second growth stands of Douglas-fir averaged slightly better than 80 percent of the normal yield table values. Timber Trends in Western Oregon and Western Washington (USDA 1963) reduced gross yields by 15 percent. The D.N.R. of Washington State reduced yields by 30 percent for extensively managed stands and by 15 percent for intensively managed stands in their harvest schedule planning (Hoyer 1975). Based on these historic precedents, a 15 percent reduction was selected.

For legitimate comparisons to be made it was necessary to standardize the utilization rule and log scale measurement for all yield predictors. This was done by using total cubic feet, including top and stump, for all trees as the volume measure throughout the study. The only exception was the DNR Empirical Yields (Chambers, Wilson 1972) use all trees greater than seven inches diameter breast height as the standard rather than all trees. The effect of this should be minor because by the time harvesting will take place most trees will be larger than seven inches diameter. The effect is that DNR yields will be slightly conservative for younger age classes relative to what they would be if all trees were included.

Total cubic feet, including top and stump (CVTS), was selected for three reasons; it was available for all the yield predictors, it represents biological potential, and it simplifies the problem of guessing future utilization standards. Scribner board foot volume, which is still the most commonly used log rule for Douglas-fir in the Pacific Northwest, is not suitable for analytical use (Meyer 1930). Evidence indicates it is much more variable than cubic foot volumes, especially for young stands or ones on poor sites. This can result in large, erratic differences between actual stand yields and those in yield tables. Cubic foot volume is a more consistent measure. In addition, the relation between cubic foot volume percent normality and that for basal area is very regular (McArdle et al. 1930, Chambers 1980a). The importance of this will become clear later.

There are disadvantages to using cubic feet rather than Scribner board feet. Because cubic feet is currently not in widespread use operationally the applicability of results of the present study is reduced. Cubic foot harvest levels would have to be converted to Scribner volume in order to implement them in the field. This is difficult because of the inconsistent relation between Scribner volume and cubic feet. The relative differences reported for cubic feet are not necessarily the same as would be reported if Scribner volumes were used.

This problem is compounded by management intensification in the form of commercial and precommercial thinning, as simulated in the present study. Use of cubic volume tends to hide a benefit of those practices which is to increase merchantable Scribner volume through accelerated diameter growth. A failing of the present study is that it ignores this quality difference resulting from thinning.

Bulletin 201 (McArdle et al. 1930) was used as the base yield set for extensive management. It was developed from data gathered during the first half of this century from single plot measurements in fully, normally stocked natural stands in the Pacific Northwest. There was a range in density of these fully stocked stands in terms of volume per acre so the average was defined as 100 percent stocked. This average became the standard or normal stocking in these yield tables. A problem with their use comes with applying them to stands which aren't normal throughout their life, either naturally understocked or overstocked relative to the standard or altered via thinning operations.

Bulletin 201 was used as the base because historically it has been the most widely used yield information for Douglas-fir, even though its shortcomings have long been known (Meyer 1930). It was also selected as the base because it had already been formulated by Beuter et al. (1976) for use in the harvest scheduling simulation model TREES (Tedder et al. 1980), used in the present study as the computational tool.

Formulation was done for three different site class levels using the 100-year basis site classification system of McArdle et al. (1930); high site (indexes 170 to 200), medium site (140), and low site (80 to 110). Bulletin 201 yield information was supplemented with Forest Service yield information for ages 170 to 300. Multiple regression techniques were used by Beuter et al. (1976) to construct equations predicting cubic foot yield as a function of age, $(age)^2$, and $(age)^3$. These equations are found in the TREES model as the default, yield-generating equations of the E-FILE (Tedder et al. 1980).

For other yields to be comparable to the base they had to be generated using the same site productivity classes used in developing the base yields. Yields generated from the regression equations just described were compared with those of Bulletin 201, Table 2. Linear interpolation was used to assign a site class to each age class. These are shown in Table 1. Table 1 also shows equivalent King's 50-year basis site indexes, obtained from King (1966), Table 9 by using linear interpolation. These sites were needed for generating yields for the DNR Empirical Yield Tables (Chambers, Wilson 1972) and for Hoyer's Natural Stand Yields (Hoyer 1975).

DFIT is a computerized single stand yield simulator

TABLE 1. STANDARDIZED SITE INDEXES

Age	McArdle 100-year Site			King's 50-year Site		
	High	Medium	Low	High	Medium	Low
25	200.0	149.4	103.2	161.0	125.0	91.2
35	191.0	144.0	101.1	152.7	118.8	87.8
45	185.7	141.0	100.0	147.0	114.7	85.5
55	182.0	139.0	99.1	142.5	110.4	83.3
65	181.4	139.0	98.9	140.7	110.2	81.3
75	181.4	139.0	99.1	138.7	108.3	79.3
85	182.0	139.5	99.5	138.2	106.7	78.7
95	183.7	140.4	100.0	136.6	105.0	76.5
105	186.1	141.5	100.7	136.6	104.2	75.5
115	188.5	142.6	101.3	136.9	103.5	74.0
125	190.0	143.5	101.8	136.9	103.0	73.5

developed by Forest Service personnel at the Pacific Northwest Forest and Range Experiment Station. It has the capacity to simulate extensively or intensively managed stands. The DFIT yields for extensive management through age 125 were generated using the age - McArdle 100-year site combinations of Table 1 in equations 0-1 and 0-9 of Bruce et al. (1977) for natural stands:

$$A_B = A_T - 13.22 + 0.033S$$

$$\log V = 1.9628 - 12.4083/A_T - 1.7408/(A_B)^{0.25} + 1.3176\log S$$

where: A_B is breast height age

A_T is total age

S is McArdle 100-year basis site index

V is total cubic foot volume per acre

Beyond age 125 these equations gave unreasonably high volumes per acre; probably because of extrapolating beyond the data base. Yields for ages 135 through 305 were obtained by adding the difference between two Bulletin 201 yields to the corresponding younger yield of DFIT. For example, to get the DFIT yield for age 135, the difference of Bulletin 201 yields for ages 125 and 135 was added to the DFIT yield for age 125.

The DNR Empirical Yield Tables were developed for natural stands of Douglas-fir in western Washington. An empirical yield table is also called a variable density yield table. Contrary to a normal yield table that uses only fully stocked stands as its base, empirical yield tables use average stand conditions found in nature. The particular yields used for this study are for 100 percent density stands which makes them compatible with the other yield predictors. As previously noted, these yields were developed using trees seven inches or larger in diameter at breast height. With current merchantibility limits, that is probably a more realistic standard to use than all trees. For reasons cited earlier the difference will be small.

As with the DFIT yields, these yields were generated by using combinations of age and site from Table 1 in the following equation from Chambers, Wilson (1972):

$$\begin{aligned} CVTS = {} & -938.33423 + (2.01933 \times Age_B \times Site \times PNBA) \\ & -(21.28009 \times Age_B \times PNBA) + (41.49121 \times Age_B) \\ & -(.51870 \times Age_B \times Age_B) - (1567.56665 \times PNBA) \end{aligned}$$

where: CVTS is total cubic foot volume, top and stump

Age_B is breast height age

Site is King's 50-year basis site index

PNBA is percent normal basal area (in this case, always 1.0)

and where:

Age_B = Total Age - 6 years for high site

Age_B = Total Age - 8 years for medium site

Age_B = Total Age - 9 years for low site

Yields from this equation were used for age classes up to and including 105 years. Yields for ages 115 to 305 were obtained in the same manner as the DFIT yields for older age classes.

Hoyer (1975) developed normal yield tables for Douglas-fir on a 50-year site index basis. This was done by combining information from Bulletin 201 with that from two papers by Curtis (Curtis 1966, Curtis 1967). Hoyer describes the method used for merging the information into a single set of tables in Appendix C of his 1975 paper on managed stand simulation. The tables themselves appear in the appendix of that paper as Tables 14-A through 14-E. Yields from this source used in the present study came from those tables using linear interpolation to most closely approximate the appropriate 50-year site index. This source provided yields for age classes through age 95. Yields for ages beyond 95 were obtained using the method described earlier.

The final set of yields for extensive management are those of Bulletin 201 less 15 percent. These were obtained by modifying the appropriate yield functions developed by Beuter et al. (1976) that are found in the TREES model default file, the E-FILE. The five sets of extensive management yields used in this study are shown in Tables 2A to 2C and Bulletin 201 yields are shown in Figures 1A to 1C.

TABLE 2A. EXTENSIVE MANAGEMENT YIELDS - HIGH SITE
TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	DNR	Hoyer's Natural	Bull. 201 Less 15%
25	3,309	4,545	3,868	4,000	2,812
35	5,916	7,204	6,586	7,150	5,029
45	8,303	9,438	9,070	9,809	7,058
55	10,480	11,297	11,339	11,988	8,908
65	12,456	13,075	13,644	14,232	10,588
75	14,241	14,676	15,745	16,282	12,105
85	15,845	16,163	17,900	18,419	13,468
95	17,277	17,650	19,734	20,401	14,686
105	18,548	19,136	21,719	21,672	15,766
115	19,668	20,552	23,135	22,791	16,718
125	20,645	21,772	24,355	23,769	17,549
135	21,491	22,648	25,231	24,615	18,268
145	22,215	23,342	25,925	25,338	18,883
155	22,826	23,952	26,536	25,950	19,402
165	23,334	24,462	27,045	26,458	19,835
175	23,751	24,878	27,461	26,874	20,188
185	24,084	25,211	27,794	27,207	20,472
195	24,344	25,471	28,054	27,468	20,693
205	24,541	25,668	28,251	27,665	20,860
215	24,684	25,811	28,394	27,808	20,982
225	24,784	25,911	28,494	27,908	21,067
235	24,851	25,977	28,560	27,974	21,124
245	24,893	26,019	28,602	28,016	21,160
255	24,921	26,047	28,630	28,044	21,184
265	24,932	26,057	28,640	28,054	21,193
275	24,932	26,057	28,640	28,054	21,193
285	24,932	26,057	28,640	28,054	21,193
295	24,932	26,057	28,640	28,054	21,193
305	24,932	26,057	28,640	28,054	21,193

TABLE 2B. EXTENSIVE MANAGEMENT YIELDS - MEDIUM SITE
TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	DNR	Hoyer's Natural	Bull. 201 Less 15%
25	2,482	2,954	1,979	2,500	2,110
35	4,427	4,843	4,139	5,087	3,763
45	6,206	6,461	6,102	7,142	5,275
55	7,827	7,829	7,776	8,563	6,653
65	9,298	9,125	9,645	10,239	7,903
75	10,624	10,259	11,172	11,835	9,031
85	11,815	11,315	12,566	12,756	10,043
95	12,877	12,320	13,773	13,871	10,946
105	13,818	13,273	14,984	14,812	11,746
115	14,646	14,166	15,877	15,640	12,449
125	15,367	14,981	16,692	16,361	13,062
135	15,990	15,604	17,315	16,984	13,592
145	16,521	16,135	17,846	17,515	14,043
155	16,969	16,583	18,294	17,963	14,424
165	17,340	16,954	18,665	18,334	14,739
175	17,642	17,296	19,007	18,636	14,996
185	17,883	17,537	19,248	18,877	15,201
195	18,070	17,724	19,435	19,064	15,359
205	18,210	17,864	19,575	19,204	15,479
215	18,311	17,965	19,676	19,305	15,564
225	18,381	18,035	19,746	19,375	15,623
235	18,426	18,080	19,791	19,420	15,662
245	18,454	18,108	19,819	19,448	15,686
255	18,474	18,128	19,839	19,468	15,702
265	18,478	18,132	19,843	19,472	15,706
275	18,478	18,132	19,843	19,472	15,706
285	18,478	18,132	19,843	19,472	15,706
295	18,478	18,132	19,843	19,472	15,706
305	18,478	18,132	19,843	19,472	15,706

TABLE 2C. EXTENSIVE MANAGEMENT YIELDS - LOW SITE TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	DNR	Hoyer's Natural	Bull. 201 Less 15%
25	1,406	1,729	631	1,561	1,195
35	2,523	2,966	2,273	3,356	2,144
45	3,546	4,045	3,765	4,683	3,013
55	4,478	4,958	5,064	5,905	3,806
65	5,324	5,777	6,193	6,774	4,525
75	6,089	6,523	7,137	7,657	5,175
85	6,777	7,207	8,112	8,506	5,760
95	7,391	7,838	8,681	9,059	6,281
105	7,936	8,441	9,290	9,604	6,745
115	8,416	8,992	9,841	10,084	7,153
125	8,835	9,495	10,344	10,503	7,509
135	9,198	9,858	10,707	10,866	7,818
145	9,509	10,169	11,018	11,177	8,082
155	9,772	10,432	11,281	11,440	8,306
165	9,992	10,652	11,501	11,660	8,492
175	10,172	10,832	11,681	11,840	8,645
185	10,316	10,976	11,825	11,984	8,767
195	10,429	11,089	11,938	12,097	8,864
205	10,516	11,176	12,025	12,184	8,937
215	10,580	11,240	12,089	12,248	8,991
225	10,625	11,284	12,133	12,293	9,030
235	10,656	11,315	12,164	12,324	9,056
245	10,677	11,336	12,185	12,345	9,074
255	10,692	11,351	12,200	12,360	9,087
265	10,698	11,356	12,205	12,365	9,091
275	10,698	11,356	12,205	12,365	9,091
285	10,698	11,356	12,205	12,365	9,091
295	10,698	11,356	12,205	12,365	9,091
305	10,698	11,356	12,205	12,365	9,091

FIGURE 1A. EXTENSIVE MANAGEMENT YIELDS

HIGH SITE
BULLETIN 201

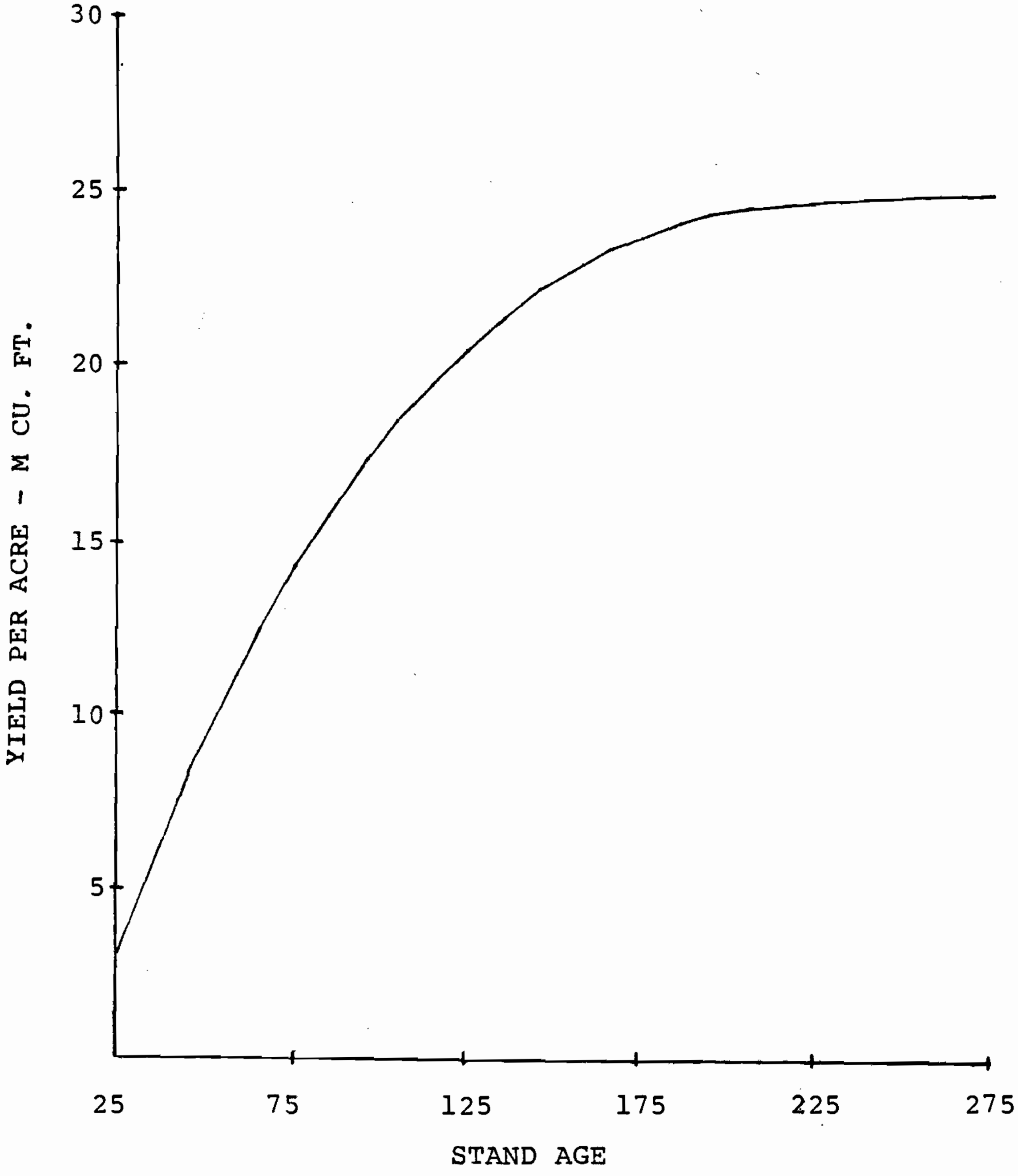


FIGURE 1B. EXTENSIVE MANAGEMENT YIELDS

MEDIUM SITE
BULLETIN 201

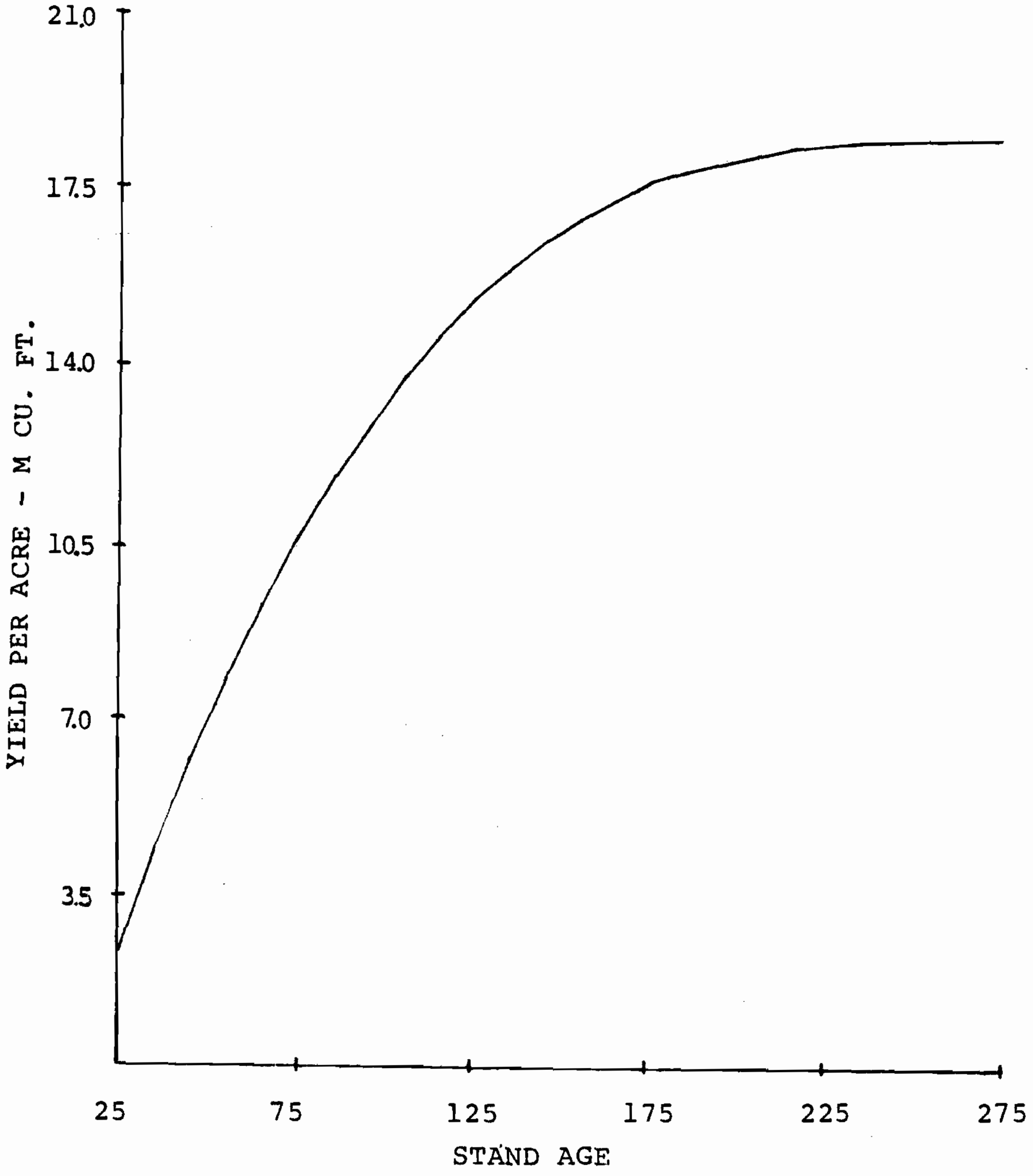
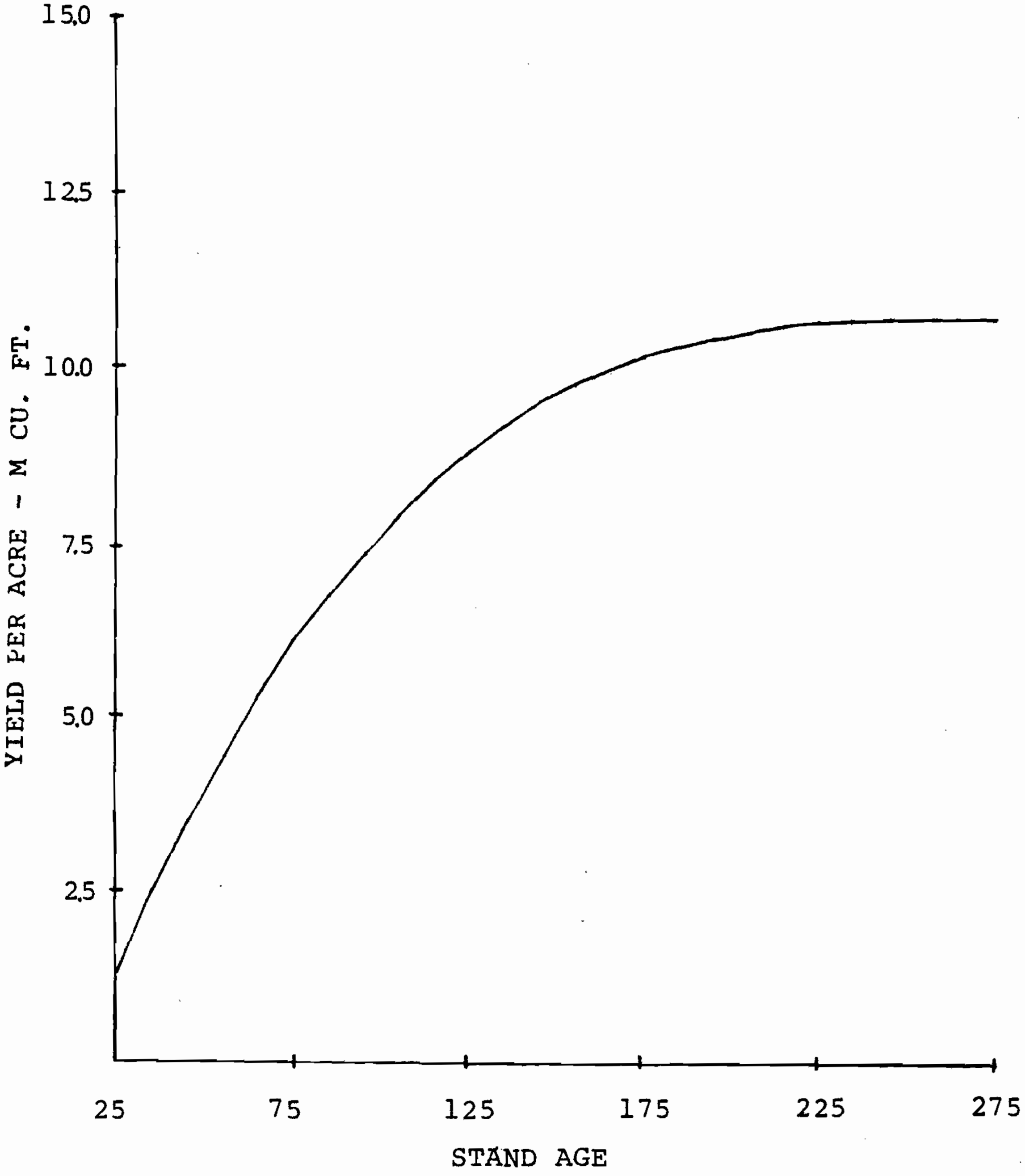


FIGURE 1C. EXTENSIVE MANAGEMENT YIELDS

LOW SITE
BULLETIN 201



The original project proposal called for comparison of several intensive management yield predictors. Because of unavailability or incompatibility this objective was achieved in only a limited way. Three sets of yields were used for intensive management comparisons. They were Bulletin 201 as modified by Beuter et al. (1976) for intensive management, DFIT, and the former less 15 percent.

The intensified management regime includes the practices of commercial and precommercial thinning. Neither intensive management yields of Bulletin 201 nor those of DFIT explicitly reflect increased yields from commercial thinning. The primary benefits of commercial thinning are not explicitly considered in this study with the exception of better utilization of mortality. Other benefits are an increased diameter growth rate of remaining trees and an earlier financial return on investment. An increase in the total production of wood is not a significant benefit. The standard normal yields used in the simulation for the regime with commercial thinning are the same as those for extensive management.

All yield predictors used in this study show net live volumes, not gross production. Mortality estimates for all yield predictors were made the same by using mortality equations in the default file of the TREES model. These were developed by Beuter et al. (1976). It should be noted that even though mortality salvage was permitted in low management intensity simulations, none occurred because the minimum needed to trigger such an activity, set at 800 cubic feet per acre, was never met.

Effects of precommercial thinning are better represented in this study, though some, such as those resulting from larger tree diameters, are not demonstrated. Both modified Bulletin 201 and DFIT yields show increases in total cubic foot yields from precommercial thinning. Bulletin 201 yields for this practice come from equations developed by Beuter et al. (1976). This was done for high site and medium site by shifting the yields for extensive management up five years in time. For example, 4,427 cubic feet per acre is the predicted yield for a fully stocked, medium site, 35 year old stand managed extensively. If the same stand was precommercially thinned 4,427 cubic feet would be expected when it became 30 years old. A ten year shift was made for low site.

DFIT accounts for precommercial thinning by increasing the site index that is used in the yield equations as follows (Bruce et al. 1977):

$$S_A = S[1 + (210 - S)^2 / 90000]$$

where: S_A is the adjusted site index

S is the original site index

Adjusted site indexes were computed for each age - McArdle

100-year site index combination of Table 1 and are shown in Table 3. Age-adjusted site combinations were then used in equations 0-1 and 0-9 of Bruce et al. (1977) to approximate the expected yields after precommercial thinning. The effect of this approximation is to slightly overestimate the cubic foot yields for the younger age classes, i.e., 25 and 35 years, relative to the yield prediction from a DFIT precommercial thinning simulation routine. Yields for older age classes are less affected.

This approximation method was used instead of the DFIT precommercial thinning simulation routine because of a combination of the yield format required by TREES and the nature of the DFIT routine. The TREES model requires standard normal yield volumes per acre by age class by management regime for a fully stocked stand, in this case for one precommercially thinned and then left alone. If done using the DFIT routine no mortality is permitted after precommercial thinning, which adjusts the simulated stand to 400 trees per acre. A 45 year old precommercially thinned stand would have 400 trees per acre but so would a 90 year old stand. Assuming no commercial thinning as required for the standard normal yields, no natural mortality is simulated by DFIT. That was not considered realistic so the routine was not used. In addition, site cannot be varied with age in the routine as Table 1 shows is necessary for

TABLE 3. ADJUSTED SITE INDEXES FOR INTENSIVE MANAGEMENT DFIT YIELDS

Age	Original Site	Adjusted Site
	High	
25	200.	200.2
35	191.	191.8
45	185.7	186.9
55	182.	183.6
65	181.4	183.
75	181.4	183.
85	182.	183.6
95	183.7	185.1
105	186.1	187.3
115	188.5	189.5
125	190.	190.8
	Medium	
25	149.4	155.5
35	144.	151.
45	141.	148.5
55	139.	146.8
65	139.	146.8
75	139.	146.8
85	139.5	147.2
95	140.4	148.
105	141.5	148.9
115	142.6	149.8
125	143.5	150.6
	Low	
25	103.2	116.3
35	101.1	114.4
45	100.	113.4
55	99.1	112.6
65	98.9	112.5
75	99.1	112.6
85	99.5	113.
95	100.	113.4
105	100.7	114.1
115	101.3	114.6
125	101.8	115.0

standardization between yields.

This approximation method was used for generating intensive management DFIT yields for ages up to 125 years. The same difference technique used before was used here for ages 135 to 305 with the intensive yield set of Bulletin 201 serving as the base. Intensive management Bulletin 201 yields less 15 percent were obtained by editing appropriate E-FILE equations. Intensive management standard yields per acre are shown in Tables 4A to 4C and Bulletin 201 yields are shown in Figures 2A to 2C.

As noted, all yields used in the present study are net live volumes for normal, fully stocked stands. Unfortunately, as Meyer (1930) discussed, such stands are the exception in operational forests. It is the understocked or overstocked stand which is more common. The stocking level of an area is a measure of how fully that area is occupied by trees of the desired species, usually relative to some standard, i.e., a normal, fully stocked stand. To realistically simulate forest harvest scheduling, it is necessary to model these potential multiple stocking levels in terms of yield. The TREES model utilizes the concept of percent normality and approach to normality to accomplish this with current volume equal to the standard yield times percent normality.

While the normality concept has been strongly

TABLE 4A. INTENSIVE MANAGEMENT YIELDS - HIGH SITE
TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	Bulletin 201-15%
25	4,641	4,552	3,944
35	7,137	7,247	6,066
45	9,417	9,523	8,005
55	11,493	11,433	9,769
65	13,372	13,232	11,366
75	15,065	14,851	12,805
85	16,582	16,354	14,094
95	17,933	17,831	15,242
105	19,127	19,301	16,257
115	20,174	20,698	17,148
125	21,084	21,894	17,922
135	21,868	22,770	18,587
145	22,534	23,464	19,154
155	23,093	24,075	19,629
165	23,554	24,584	20,021
175	23,928	25,000	20,338
185	24,223	25,333	20,589
195	24,450	25,593	20,782
205	24,620	25,790	20,926
215	24,740	25,933	21,029
225	24,822	26,033	21,099
235	24,876	26,099	21,144
245	24,910	26,141	21,173
255	24,933	26,169	21,193
265	24,933	26,169	21,193
275	24,933	26,169	21,193
285	24,933	26,169	21,193
295	24,933	26,169	21,193
305	24,933	26,169	21,193

TABLE 4B. INTENSIVE MANAGEMENT YIELDS - MEDIUM SITE
TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	Bulletin 201-15%
25	3,476	3,132	2,954
35	5,337	5,175	4,536
45	7,036	6,937	5,981
55	8,581	8,431	7,293
65	9,978	9,822	8,481
75	11,236	11,039	9,550
85	12,362	12,159	10,507
95	13,362	13,218	11,358
105	14,246	14,207	12,109
115	15,019	15,127	12,766
125	15,690	15,975	13,336
135	16,267	16,598	13,826
145	16,755	17,129	14,241
155	17,164	17,577	14,588
165	17,499	17,948	14,874
175	17,770	18,290	15,105
185	17,983	18,531	15,285
195	18,145	18,718	15,423
205	18,265	18,858	15,524
215	18,350	18,959	15,596
225	18,406	19,029	15,644
235	18,442	19,074	15,674
245	18,465	19,112	15,694
255	18,478	19,132	15,705
265	18,478	19,136	15,705
275	18,478	19,136	15,705
285	18,478	19,136	15,705
295	18,478	19,136	15,705
305	18,478	19,136	15,705

TABLE 4C. INTENSIVE MANAGEMENT YIELDS - LOW SITE
TOTAL CUBIC FOOT VOLUME PER ACRE

Age	Bulletin 201	DFIT	Bulletin 201-15%
25	2,523	2,053	2,144
35	3,546	3,517	3,013
45	4,478	4,799	3,806
55	5,324	5,889	4,525
65	6,089	6,866	5,175
75	6,777	7,736	5,760
85	7,391	8,539	6,281
95	7,936	9,266	6,745
105	8,416	9,966	7,153
115	8,835	10,592	7,509
125	9,198	11,163	7,818
135	9,509	11,526	8,082
145	9,772	11,837	8,306
155	9,992	12,100	8,492
165	10,172	12,320	8,645
175	10,316	12,500	8,767
185	10,429	12,644	8,864
195	10,516	12,757	8,937
205	10,580	12,844	8,991
215	10,625	12,908	9,030
225	10,656	12,952	9,056
235	10,677	12,983	9,074
245	10,692	13,004	9,087
255	10,698	13,019	9,091
265	10,698	13,024	9,091
275	10,698	13,024	9,091
285	10,698	13,024	9,091
295	10,698	13,024	9,091
305	10,698	13,024	9,091

FIGURE 2A. INTENSIVE MANAGEMENT YIELDS

HIGH SITE
BULLETIN 201

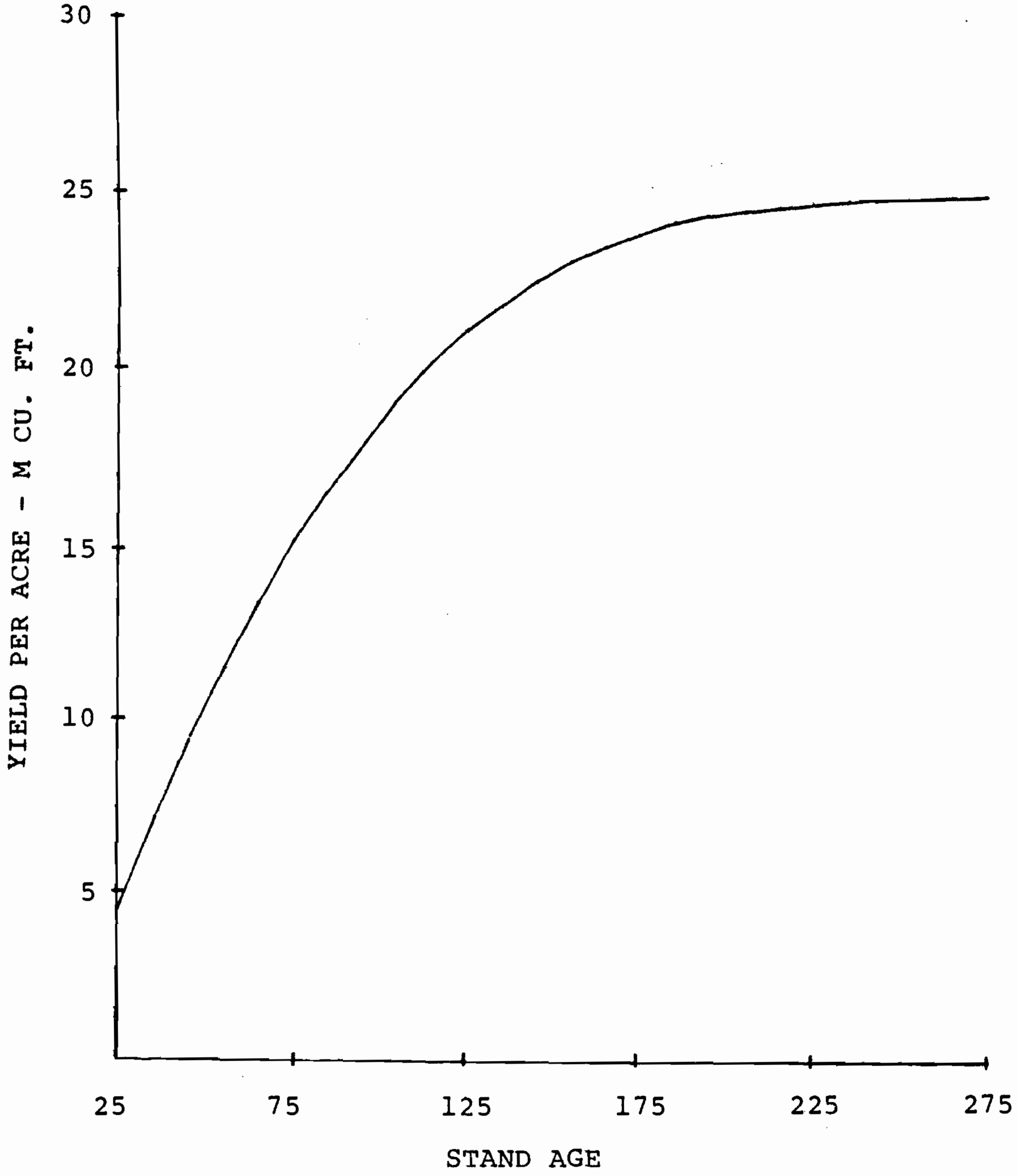


FIGURE 2B. INTENSIVE MANAGEMENT YIELDS

MEDIUM SITE
BULLETIN 201

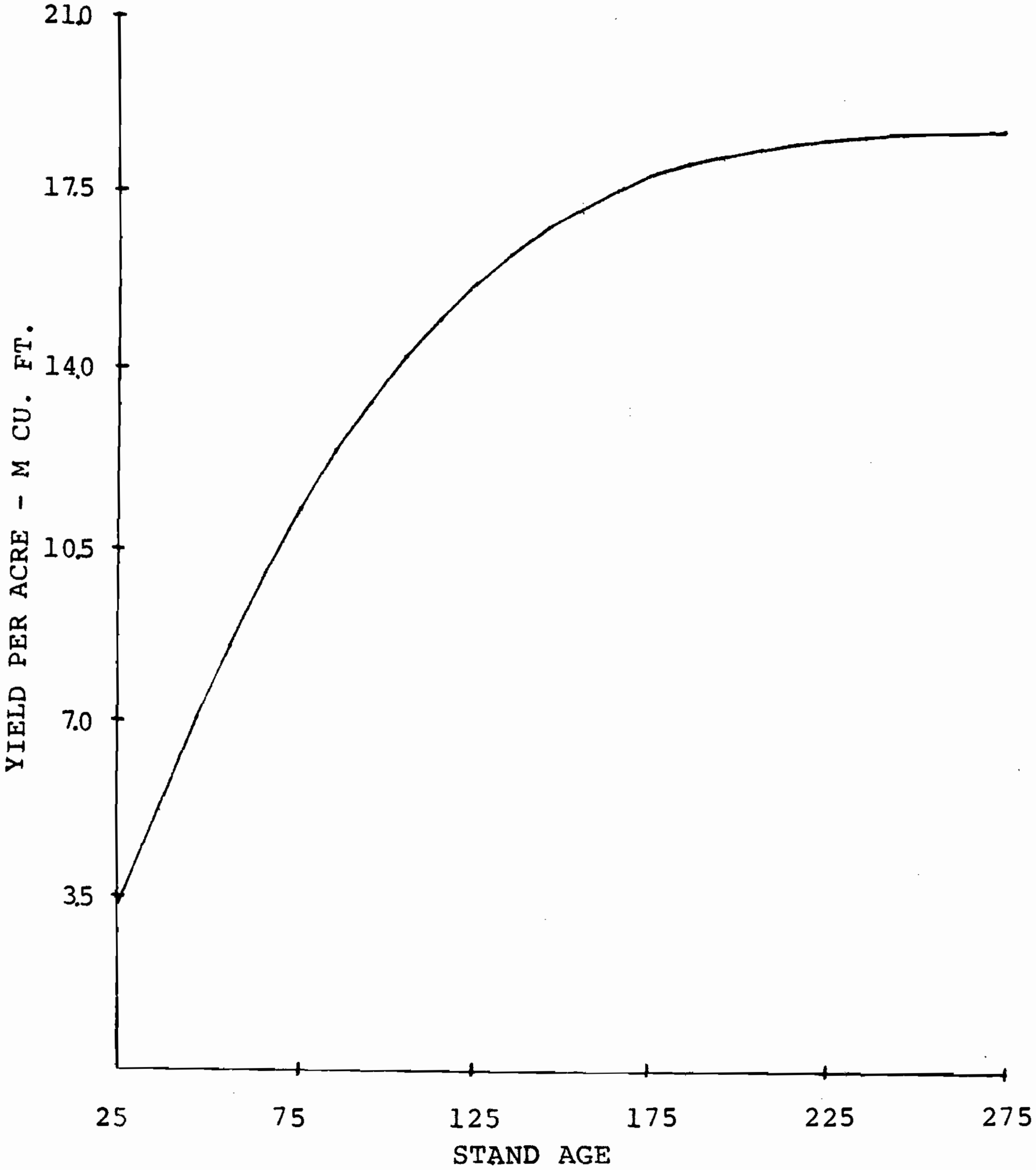
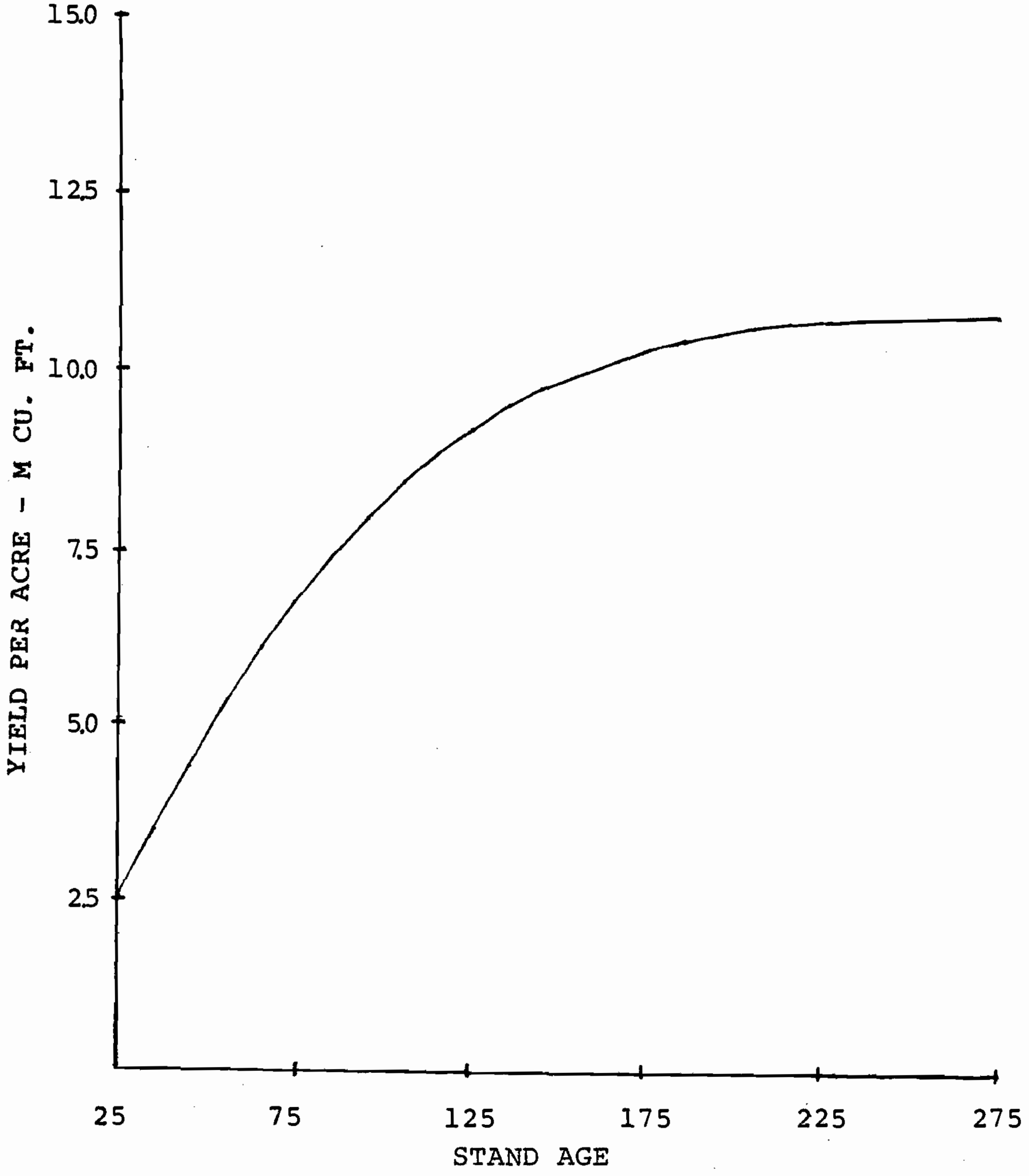


FIGURE 2C. INTENSIVE MANAGEMENT YIELDS

LOW SITE
BULLETIN 201



criticized as being too imprecise and too subjective for use in stand projections (Nelson, Bennett 1965, Curtis 1972, Ware, Clutter 1971), it is a useful tool in forest level simulations. It is certainly better than ignoring the multiple stocking level problem and current technology won't permit projecting each stand in a forest level model.

Percent stocking, or percent normality, of a stand is easily obtained by determining what percent of the standard yield table value is found in the stand for any utilization standard or measurement unit desired. In this study, percent normality is in terms of total cubic foot volume. Percent normality for different characteristics such as number of trees, basal area, or different measures of volume are not necessarily equal for a stand. Evidence suggests that for an unthinned stand percent normality for total cubic foot yield is approximately equal to that for basal area (Meyer 1930, Chambers 1980a). This finding was assumed to be true and was a key assumption in the development of approach to normality functions for different yield predictors.

The approach to normality concept suggests that understocked stands tend to approach normality over time, i.e., they become less understocked. For example, if a stand is 50 percent stocked at age t it will be something greater than 50 percent at age t + 1. There is disagreement about what the rate of approach to normality is for understocked stands of Douglas-fir. McArdle et al. (1930) suggests in Table 28 of their bulletin that the rate is a linear function with the ten year change in normality decreasing as percent stocking increases. Bell (1964) presents evidence that suggests the rates may be faster than those cited in McArdle et al. (1930). Chambers (1977a) suggests that there is inadequate evidence to demonstrate what change will take place because of accidental setbacks such as blowdown. Therefore, he holds percent stocking constant over time in his analyses for the State of Washington.

The TREES model permits the use of a linear function to model approach to normality with percent normal at time period t + 1 a function of percent normal at time period t.

$$\%N_{t+1} = b_o + b_1(\%N_t)$$

where: b_o and b_1 are empirical coefficients of the normality function. Volume in a stand is then computed by multiplying the percent normality times the standard normal volume for the age class. Because the approach to normality rate is a function of the yield predictor a unique approach to normality function was developed for each yield set.

The same approach to normality function for Bulletin 201 yields developed by Beuter et al. (1976) was used in this study for full yields and for those less 15 percent. This function generates the increase in normality table (Table 28) of McArdle et al. (1930) as revised in 1961. The same function is used for all three site levels and for extensive and intensive management regimes. It is likely that a different approach to normality would occur in a thinned stand vs. a naturally understocked stand. Because no evidence was found to support such a claim and the simulation model only accepts one approach to normality function this approximation was used. The model allows specifying an age beyond which only half the computed approach to normal is used and an age beyond which no approach to normal takes place. The two ages specified for Bulletin 201 yields were 125 and 225, respectively. The approach to normality equation for Bulletin 201, together with the equations developed for the other yield predictors, are shown in Table 5. Also shown in Table 5 are the ages for full approach to normality, half approach to normality, and no approach to normality. Computed values are shown in Tables 6A to 6C and full approach to normal is shown in Figures 3A to 3C.

The approach to normality function for DFIT was established as follows. First, as previously noted, the assumption was made that percent normality in terms of basal area equals percent normality in terms of cubic feet. This

TABLE 5. APPROACH TO NORMALITY EQUATIONS

Yield Predictor	Equation $N_{t+1} = b_o + b_1 N_t$		Full Approach Up to Age:	Half Approach Up to Age:
High Site	b_o	b_1		
Bulletin 201	.11	.90	125	225
DFIT	.15	.8963	35	155
DNR Empirical	.085	.971	35	155
Hoyer's Natural Stand	.16	.8963	55	155
Medium Site				
Bulletin 201	.11	.90	125	225
DFIT	.15	.8963	35	155
DNR Empirical	.083	.9634	35	155
Hoyer's Natural Stand	.15	.8963	45	155
Low Site				
Bulletin 201	.11	.90	125	225
DFIT	.155	.8963	35	155
DNR Empirical	.061	.9699	35	155
Hoyer's Natural Stand	.14	.8963	35	155

TABLE 6A. APPROACH TO NORMAL VALUES

HIGH SITE

N_t	N_{t+1}							
	Bulletin 201		DFIT		DNR Empirical		Hoyer's Natural	
AGE	0-125	135-225	0-35	45-155	0-35	45-155	0-55	65-155
.10	.20	.15	.24	.171	.182	.141	.25	.175
.20	.29	.245	.332	.266	.279	.24	.339	.27
.30	.38	.34	.422	.361	.376	.338	.429	.364
.40	.47	.435	.512	.456	.473	.437	.519	.459
.50	.56	.53	.601	.551	.571	.535	.608	.554
.60	.65	.625	.691	.645	.668	.634	.698	.649
.70	.74	.72	.78	.74	.765	.732	.787	.744
.80	.83	.815	.87	.835	.862	.831	.877	.839
.90	.92	.91	.96	.93	.959	.929	.967	.933
1.00	1.01	1.005	1.049	1.025	1.056	1.028	1.056	1.028
1.10	1.10	1.10	1.139	1.119	1.153	1.127	1.146	1.123
1.20	1.19	1.195	1.229	1.214	1.250	1.225	1.236	1.218
1.30	1.28	1.29	1.318	1.309	1.347	1.324	1.325	1.313

$N_{t+1} = N_t$ for ages older than those in second column of each yield set.

TABLE 6B. APPROACH TO NORMAL VALUES

MEDIUM SITE

N_t	N_{t+1}							
	Bulletin 201		DFIT		DNR Empirical		Hoyer's Natural	
AGE	0-125	135-225	0-35	45-155	0-35	45-155	0-45	55-155
.10	.20	.15	.24	.171	.179	.14	.24	.17
.20	.29	.245	.332	.266	.276	.238	.329	.265
.30	.38	.34	.422	.361	.372	.336	.419	.359
.40	.47	.435	.512	.456	.468	.434	.509	.454
.50	.56	.53	.601	.551	.565	.532	.598	.549
.60	.65	.625	.691	.645	.661	.631	.688	.644
.70	.74	.72	.78	.74	.757	.729	.777	.739
.80	.83	.815	.87	.835	.854	.827	.867	.834
.90	.92	.91	.96	.93	.95	.925	.957	.928
1.00	1.01	1.005	1.049	1.025	1.046	1.023	1.046	1.023
1.10	1.10	1.10	1.139	1.119	1.143	1.121	1.136	1.118
1.20	1.19	1.195	1.229	1.214	1.239	1.220	1.226	1.213
1.30	1.28	1.29	1.318	1.309	1.335	1.318	1.315	1.308

$N_{t+1} = N_t$ for ages older than those in the second column of each yield set.

TABLE 6C. APPROACH TO NORMAL VALUES

LOW SITE

N_t	N_{t+1}							
	Bulletin 201		DFIT		DNR Empirical		Hoyer's Natural	
AGE	0-125	135-225	0-35	45-155	0-35	45-155	0-35	45-155
.10	.20	.15	.245	.172	.158	.129	.23	.165
.20	.29	.245	.334	.267	.255	.227	.319	.26
.30	.38	.34	.424	.362	.352	.326	.409	.354
.40	.47	.435	.514	.457	.449	.424	.499	.449
.50	.56	.53	.603	.552	.546	.523	.588	.544
.60	.65	.625	.693	.646	.643	.621	.678	.639
.70	.74	.72	.782	.741	.74	.72	.767	.734
.80	.83	.815	.872	.836	.837	.818	.857	.829
.90	.92	.91	.962	.931	.934	.917	.947	.923
1.00	1.01	1.005	1.051	1.026	1.031	1.015	1.036	1.016
1.10	1.10	1.10	1.141	1.120	1.123	1.114	1.126	1.113
1.20	1.19	1.195	1.231	1.215	1.225	1.212	1.216	1.208
1.30	1.28	1.29	1.320	1.310	1.322	1.311	1.305	1.303

$N_{t+1} = N_t$ for ages older than those in the second column of each yield set.

FIGURE 3A. APPROACH TO NORMALITY
HIGH SITE

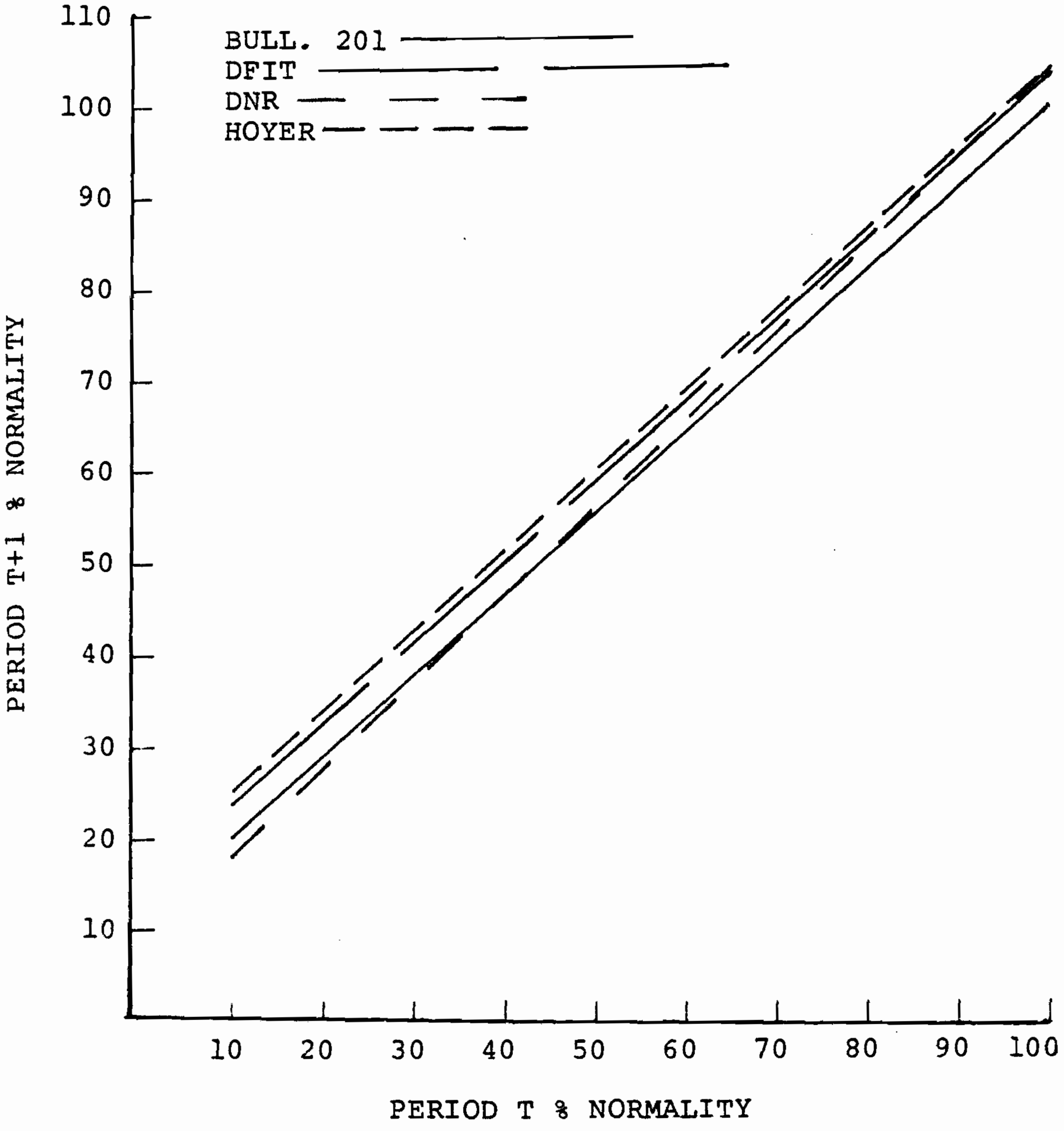


FIGURE 3B. APPROACH TO NORMALITY
MEDIUM SITE

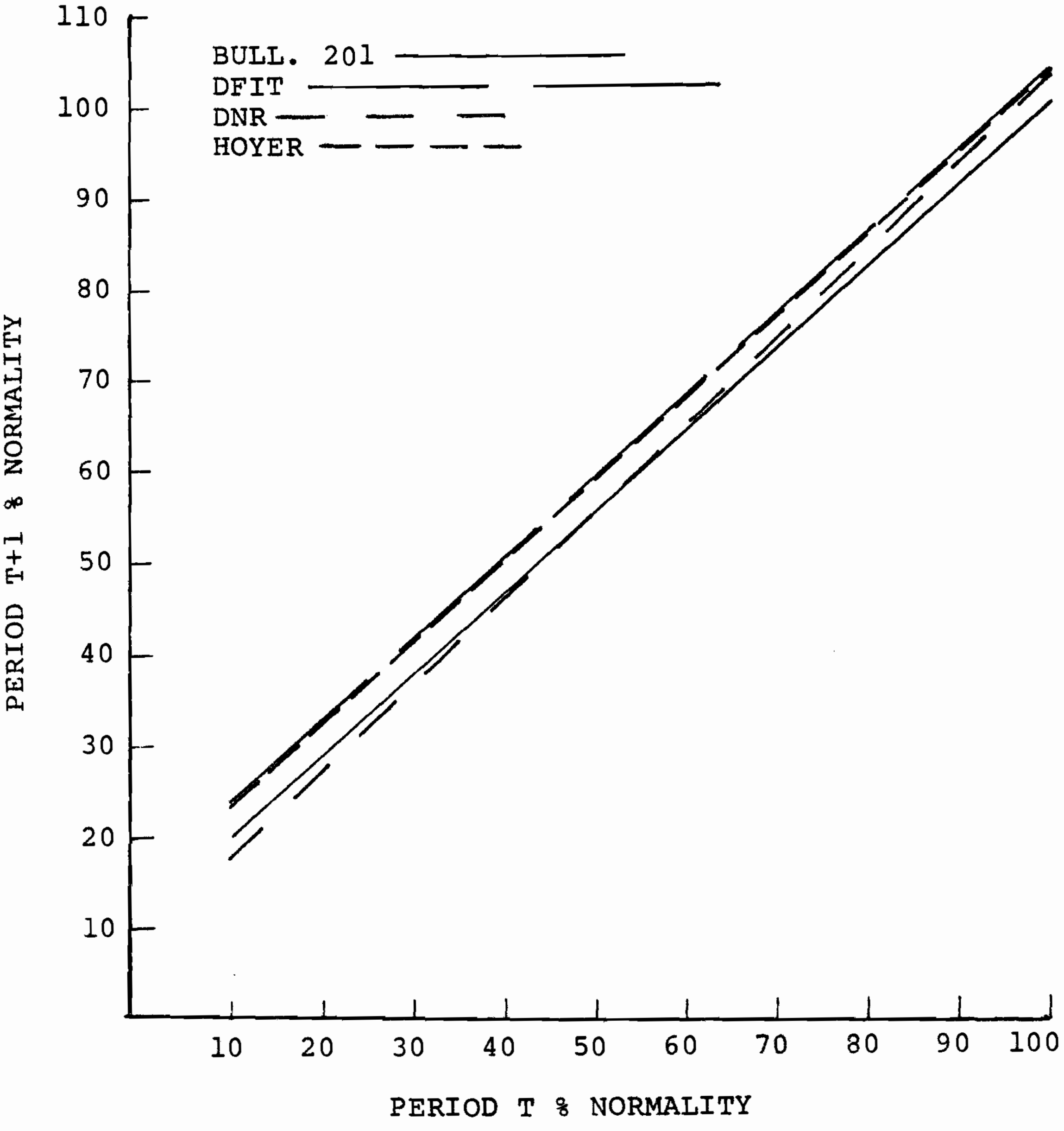
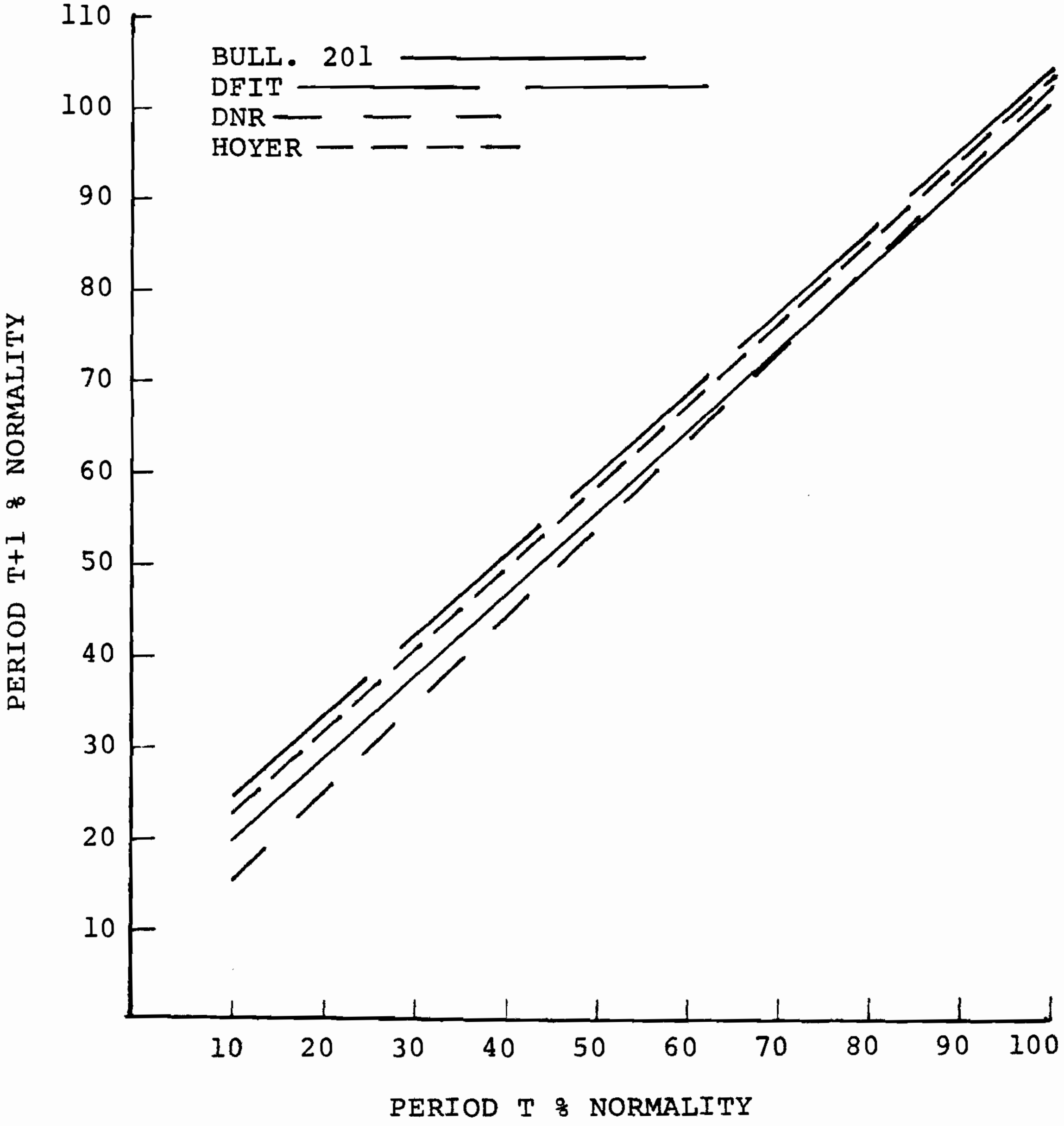


FIGURE 3C. APPROACH TO NORMALITY

LOW SITE



was necessary because percent normality in the TREES model is defined in terms of cubic feet while the growth adjustment procedure used here considered stocking in terms of basal area. It was next assumed that normal growth between age classes, or the growth that would occur during a ten year period if the stand at the beginning of the period was normally stocked, would be equal to the difference between the yield at period t and that at period t + 1 from the normal yield table. This growth was adjusted using the growth reduction multiplier from equation 2 - 3 of Bruce et al. (1977):

$$V_A = 1 - 16\ (G_{\%} - 0.5)^4$$

where: V_A is a growth reduction multiplier

$G_{\%}$ is a measure of stocking level in terms of basal area set so that $G_{\%} = 0.5$ or $V_A = 1.0$ if stocking is at the 100% level.

The multiplier has little effect on growth of understocked or overstocked stands unless they are considerably different from normal resulting in the so-called plateau effect which hypothesizes that stands over a wide range of densities have approximately the same total cubic foot production levels. V_A values for stocking levels between ten percent and 100 percent are shown in Table 7.

A short computer program was written which used growth

TABLE 7. GROWTH REDUCTION MULTIPLIER VALUES FOR DFIT APPROACH TO NORMAL CALCULATIONS

Percent Stocking	V_A
10	.344
15	.478
20	.59
25	.684
30	.76
35	.82
40	.87
45	.908
50	.937
55	.96
60	.97
65	.98
70	.992
75	.995
80	.998
85	.9985
90	.9999
95	.9999
100	1.00

reduction multipliers from Table 7 to compute percent normality in period t + 1 given age, normal volume growth, and percent normality in period t. This was done for ages 25 to 115, for stocking levels ten percent to 95 percent by increments of five, and for all three site classes.

Computed normality pairs were then used in a linear regression analysis with N_t as the independent variable and N_{t+1} as the dependent variable. Inspection of the data showed almost no difference between high and medium site and low site showed only a slightly higher rate of approach to normality. As a result an equation was developed for high and medium site and it was arbitrarily adjusted upward slightly for low site. It should be noted that inspection of data and residuals suggest that a curvilinear function passing through the origin with percent normality at period t and age at period t as independent variables would be more suitable than a strictly linear function. That approach was not followed because the simulation model used accepts only a linear function. The same approach to normality equation is used for extensive and intensive management yields.

An approach to normality equation for DNR Empirical Yields was developed in a similar way to that for DFIT. Current period and next period normality pairs were developed for current ages 30 to 90, current stocking 35 percent to 115 percent, and all three site index levels using growth tables provided by Chambers (1980b) that correspond to the DNR's Empirical Yield Tables (Chambers, Wilson 1972). These normality pairs, categorized by age class and site level, were used as the data base in a regression analysis. In this case, site index seemed to influence the approach to normal rate so three slightly different equations were developed. As with DFIT, age seemed to have an influence on the rate with age classes below 40 having somewhat higher rates than for older ones. The age-rate relationship was accounted for by developing equations that best fit the rate for younger age classes with full approach to normality while approximating the rate for older age classes with half the approach rate.

The development of the approach to normal equation for Hoyer's Natural Stand Yields proved to be difficult. Hoyer (1980) suggested computing basal area approach to normal using either the basal area growth equation in Hoyer (1975) or the net basal area growth equation from King (1970); reasonable in light of what has been noted about the equality of percent normality in terms of total cubic foot volume and basal area. A short computer program was written that computed the next period percent normality for current period stocking levels ten percent to 100 percent by increments of five, for current ages 25 to 85, and for all site index levels. One of the suggested basal area growth equations was tried. Results of this technique were extremely different from those for the other yields and so were judged unsatisfactory. Similar results occurred when the other basal area growth equation was used.

Next basal area normality changes were computed using the growing stock index curves from King (1970) which show basal area stocking levels through time. The base or normal basal area level came from the Natural Stand Tables 14A to 14E in Hoyer (1975). With only minor differences, the DFIT approach to normal equations fit the data and were used with only slight modification.

Because of uncertainty associated with these various approach to normality equations, a few sample combinations of a yield set with an approach to normality equation for a different yield predictor were used to show the significance of the approach to normality equation on calculated harvest schedules.

The next step was to obtain sample inventories to use in the simulations. It was felt that inventory characteristics such as age class distributions, stocking level distributions, and site class might influence the test results. Age class distribution includes acreage distribution and volume distribution across the range of ages. It shows such things as the old-growth component, number of acres of reproduction, or age class gaps where there are no acres in a particular age. Stocking level distribution refers to how well stocked the stands are in terms of volume per acre relative to normal yields.

Eight different sample inventories representing actual forests in western Oregon were selected from inventories developed by Beuter et al. (1976) for use in their timber supply study. Inventories were selected to represent a range of characteristics of age class and stocking level distributions. Each inventory can be considered as representing a separate forest having only one site class. The inventory gives number of acres and volume per acre by ten year age class and stocking level. No unstocked acres were permitted in the initial inventories though a small hardwood component was present in some of the stocked Douglas-fir stands. General descriptions of the eight inventories follow. Definitions of poor, medium, and well stocked are ten to 39 percent, 40 to 69 percent, and greater than or equal to 70 percent, respectively, relative to normal yield. Stocking is given as percent of total acres in the stocking level. Relative acreage and volume distributions by age class are shown in Figures 4A to 4P.

Inventory 1 - High site, younger age classes, well stocked - 0%, medium stocking - 86.5%, poorly stocked - 13.5%, 57,336 acres, 296,937,064 cubic feet.

FIGURE 4A. INITIAL ACREAGE DISTRIBUTION

INVENTORY 1

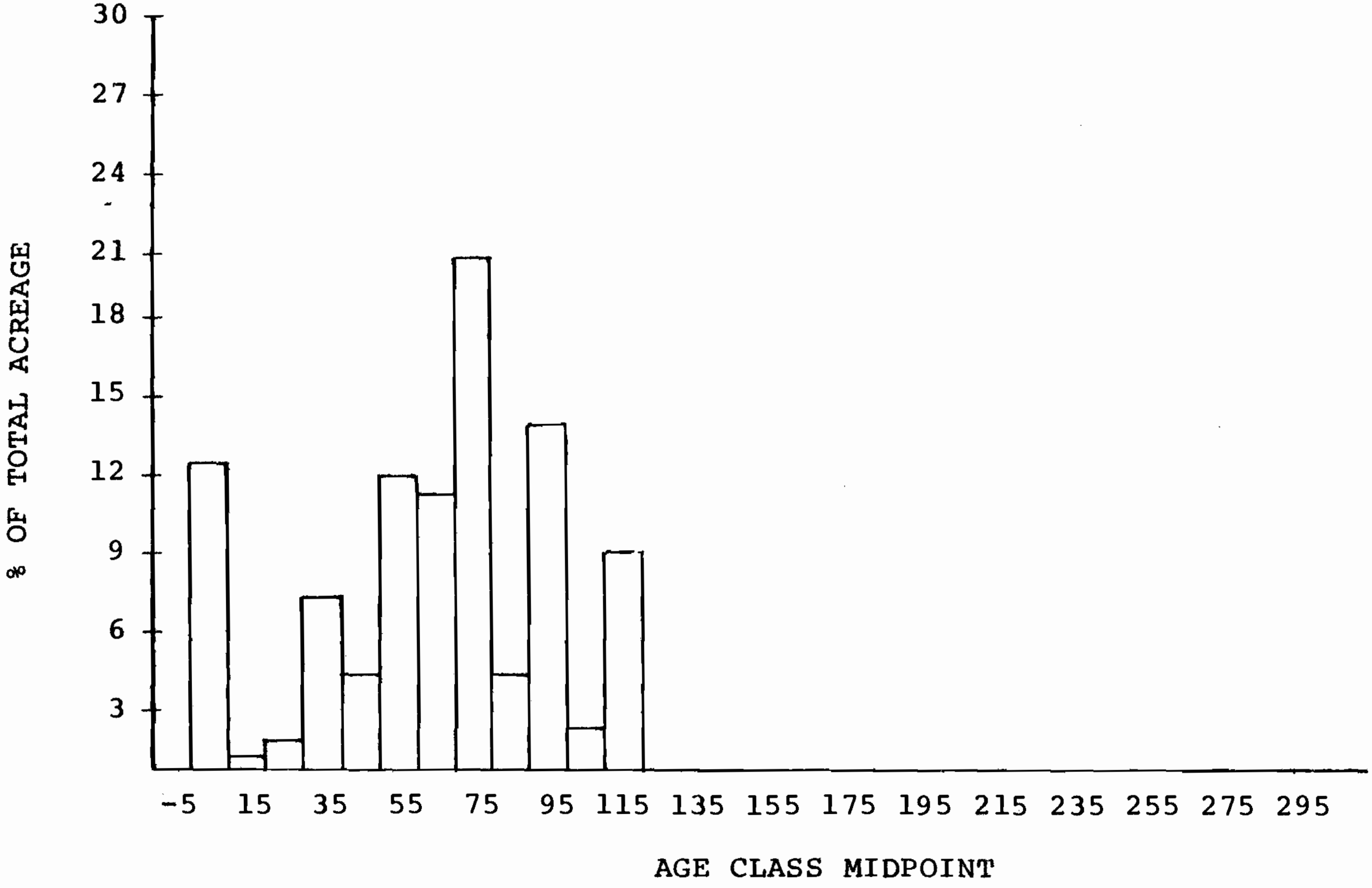


FIGURE 4B. INITIAL VOLUME DISTRIBUTION

INVENTORY 1

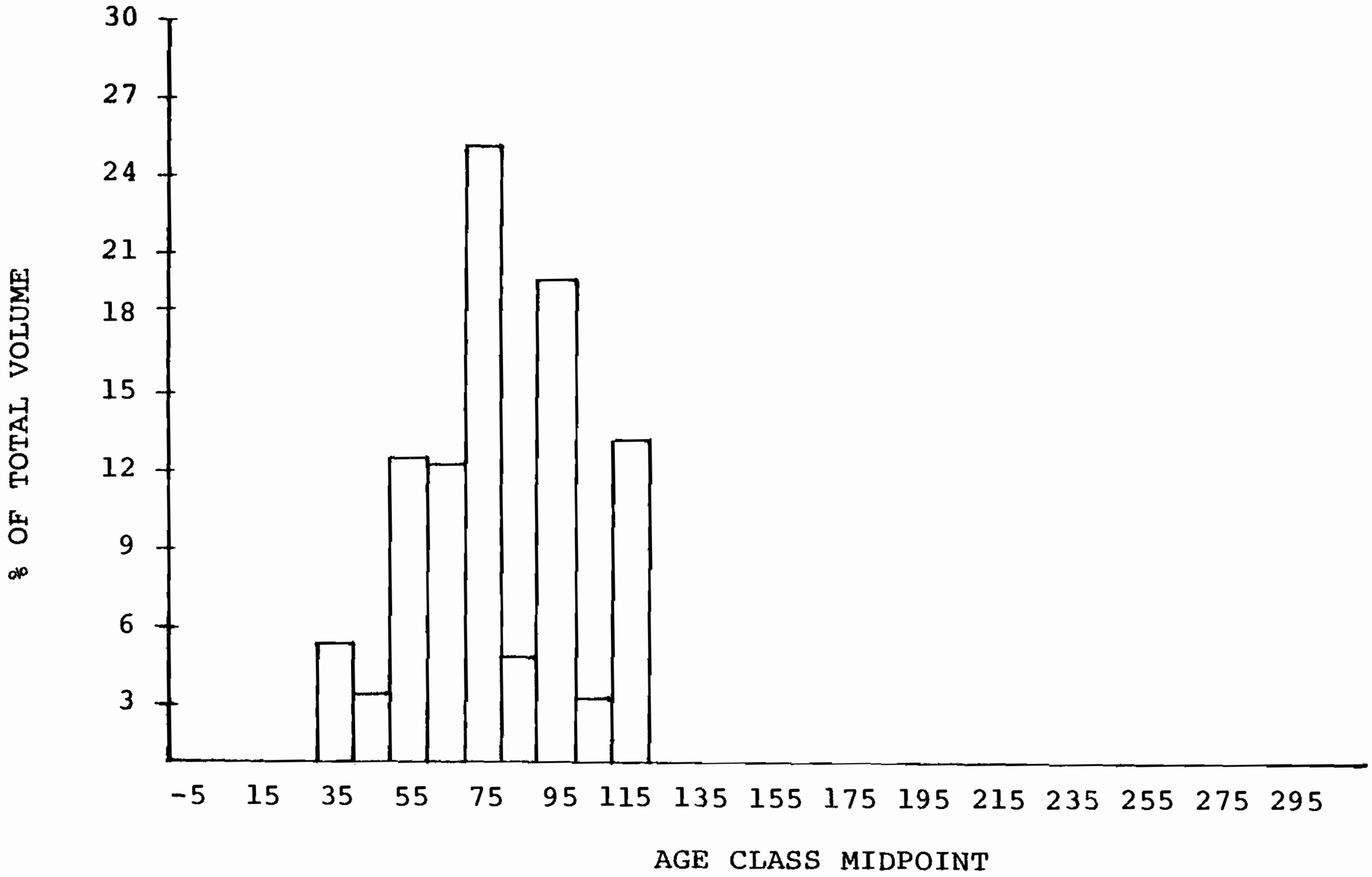


FIGURE 4C. INITIAL ACREAGE DISTRIBUTION

INVENTORY 2

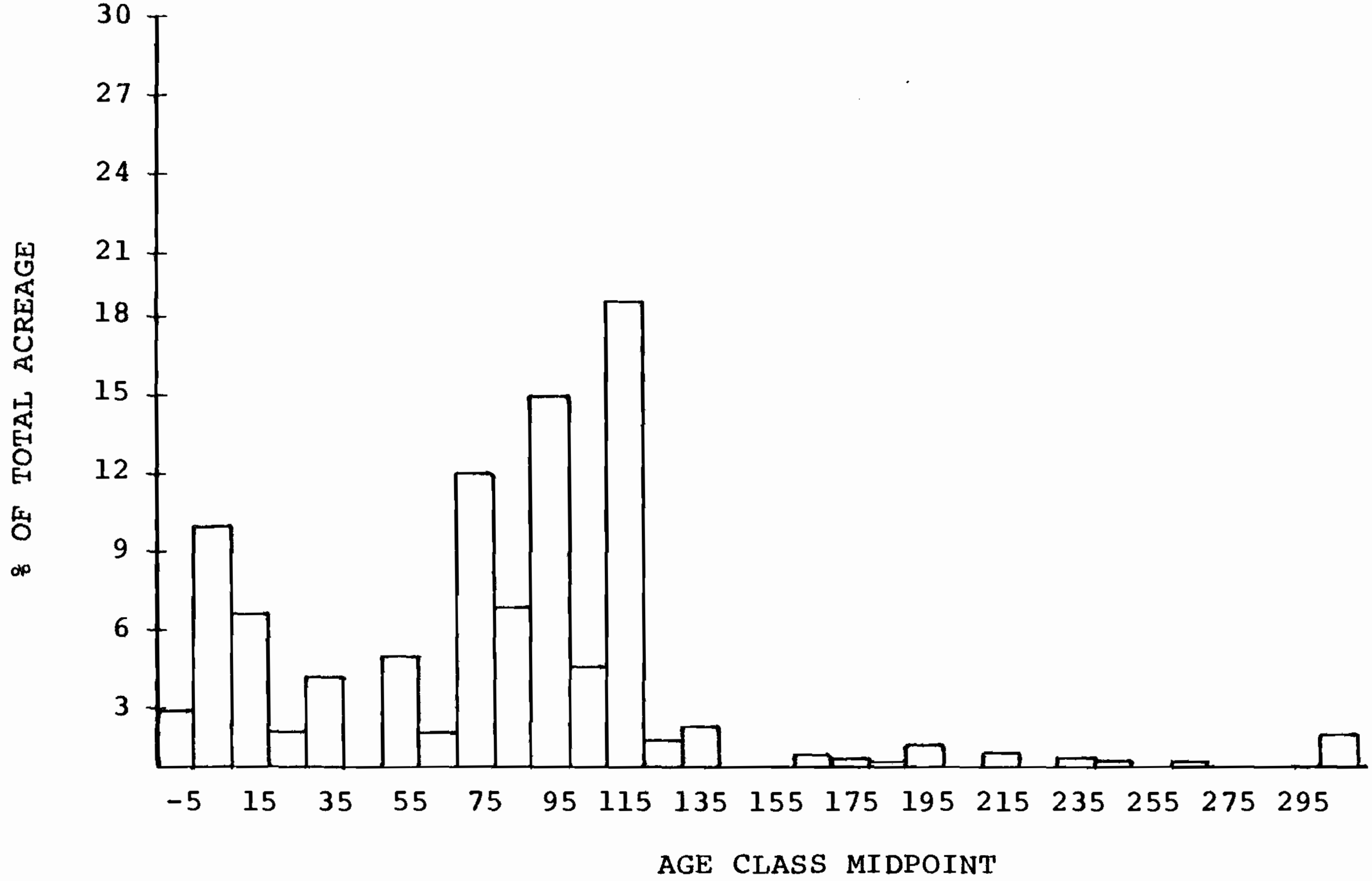


FIGURE 4D. INITIAL VOLUME DISTRIBUTION

INVENTORY 2

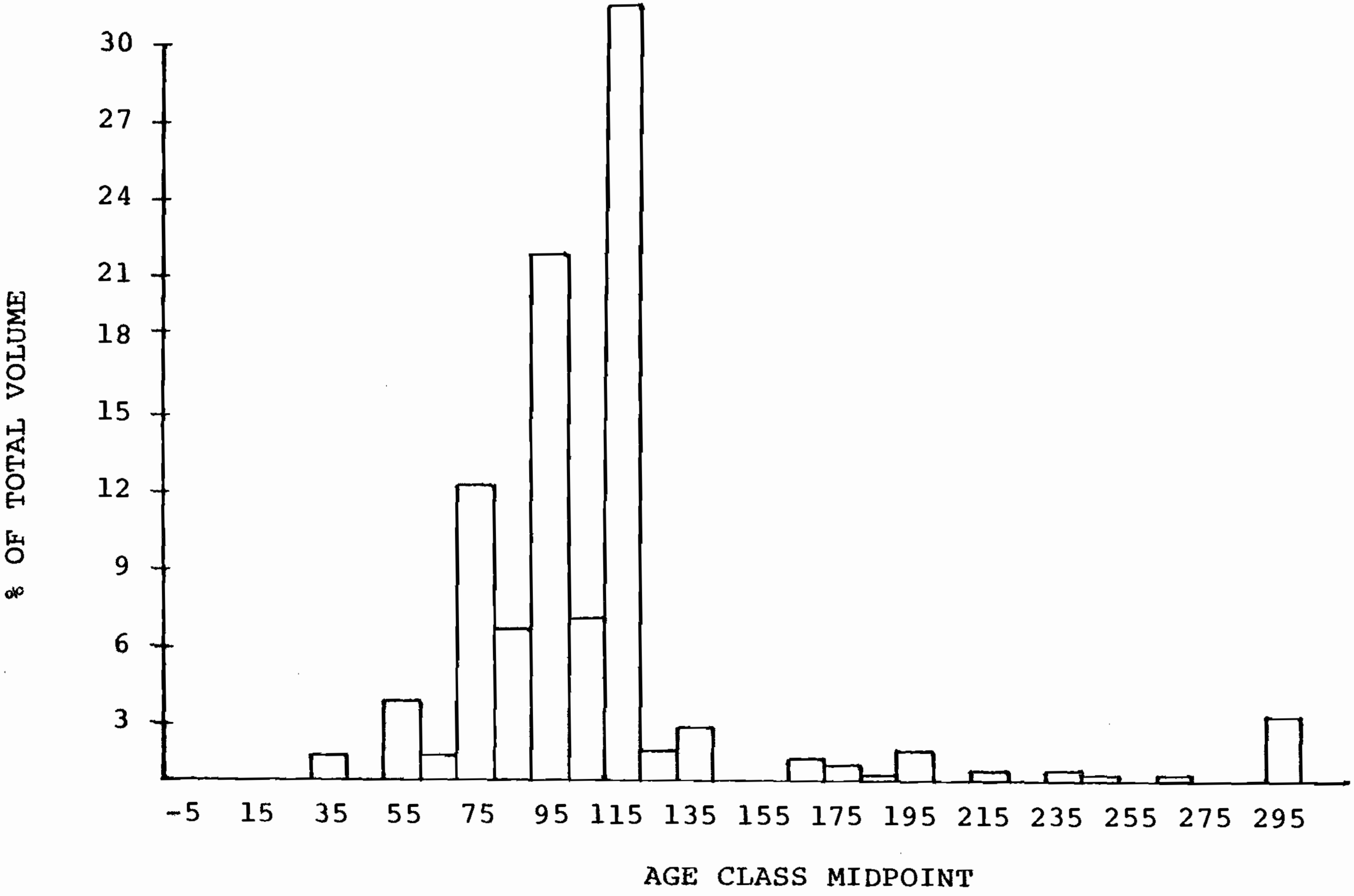


FIGURE 4E. INITIAL ACREAGE DISTRIBUTION

INVENTORY 3

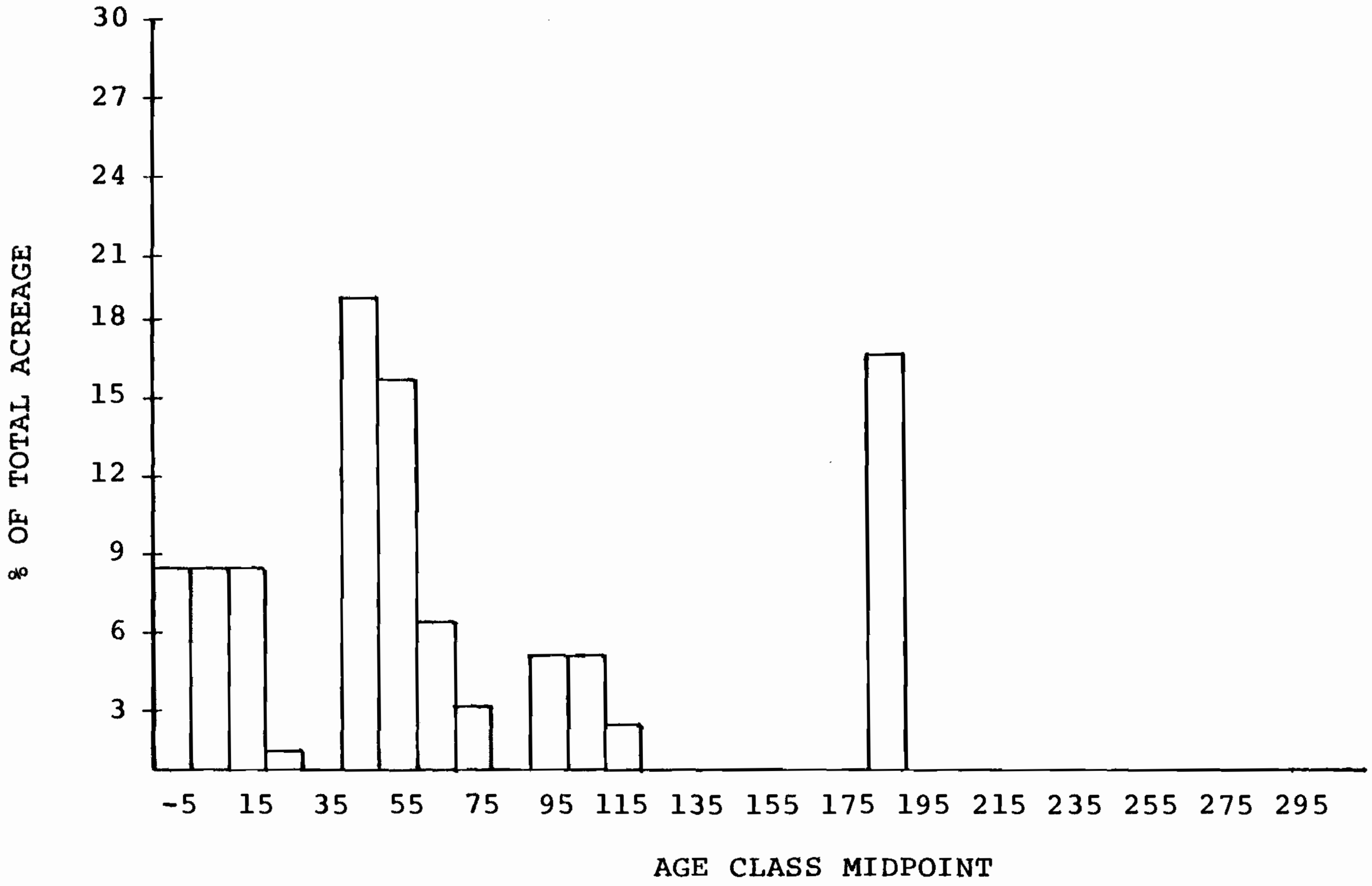


FIGURE 4F. INITIAL VOLUME DISTRIBUTION

INVENTORY 3

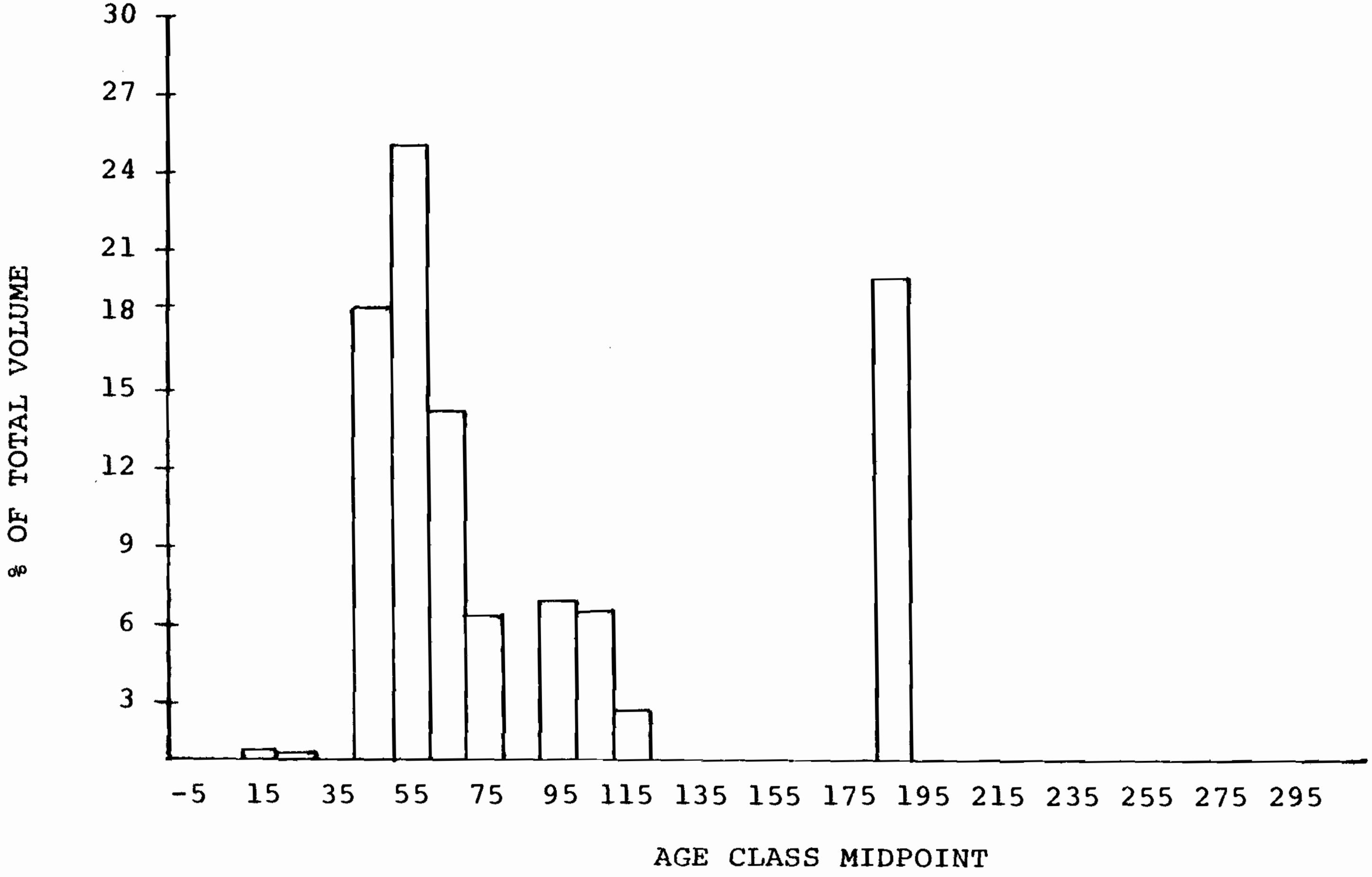


FIGURE 4G. INITIAL ACREAGE DISTRIBUTION

INVENTORY 4

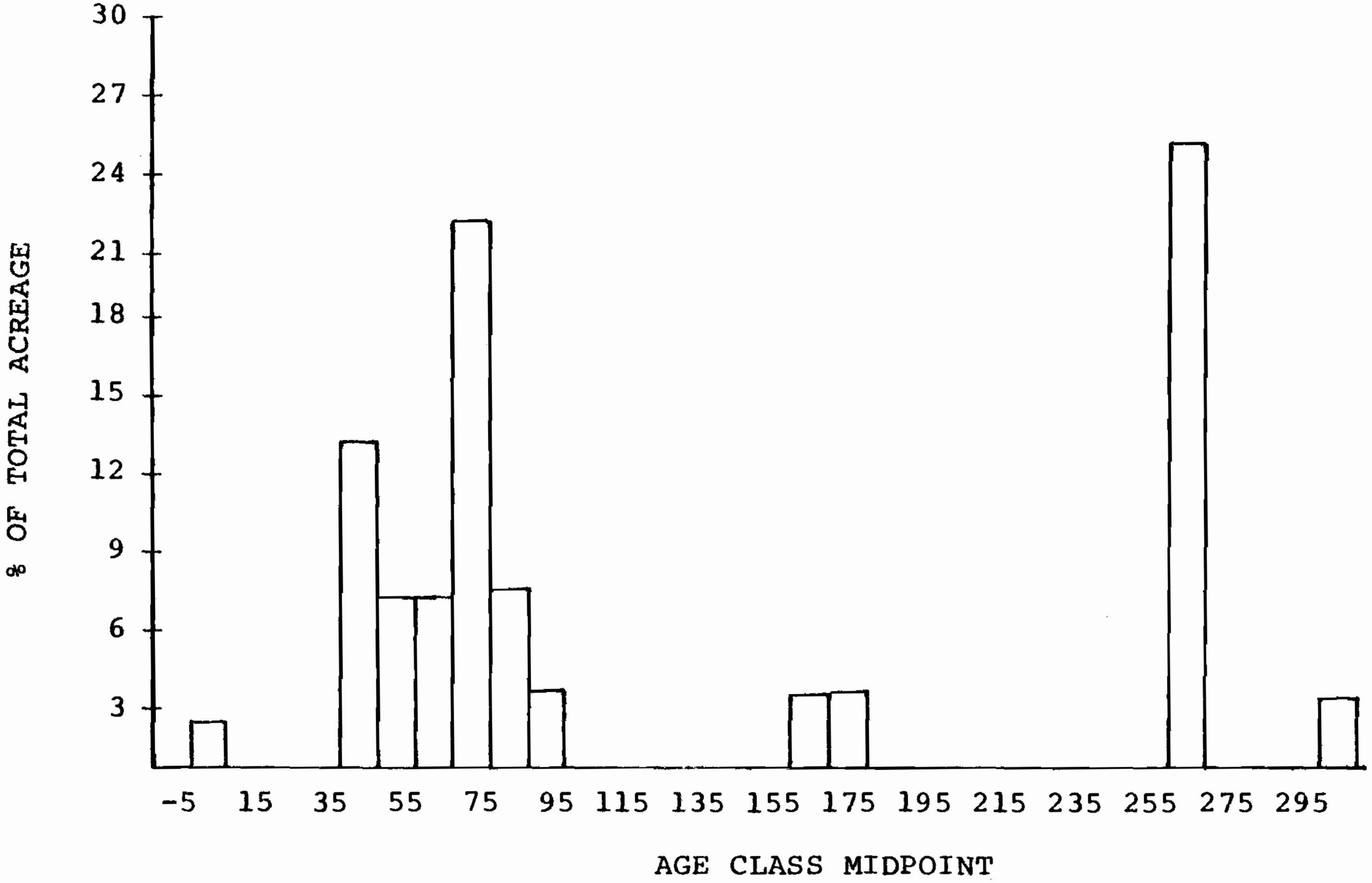


FIGURE 4H. INITIAL VOLUME DISTRIBUTION

INVENTORY 4

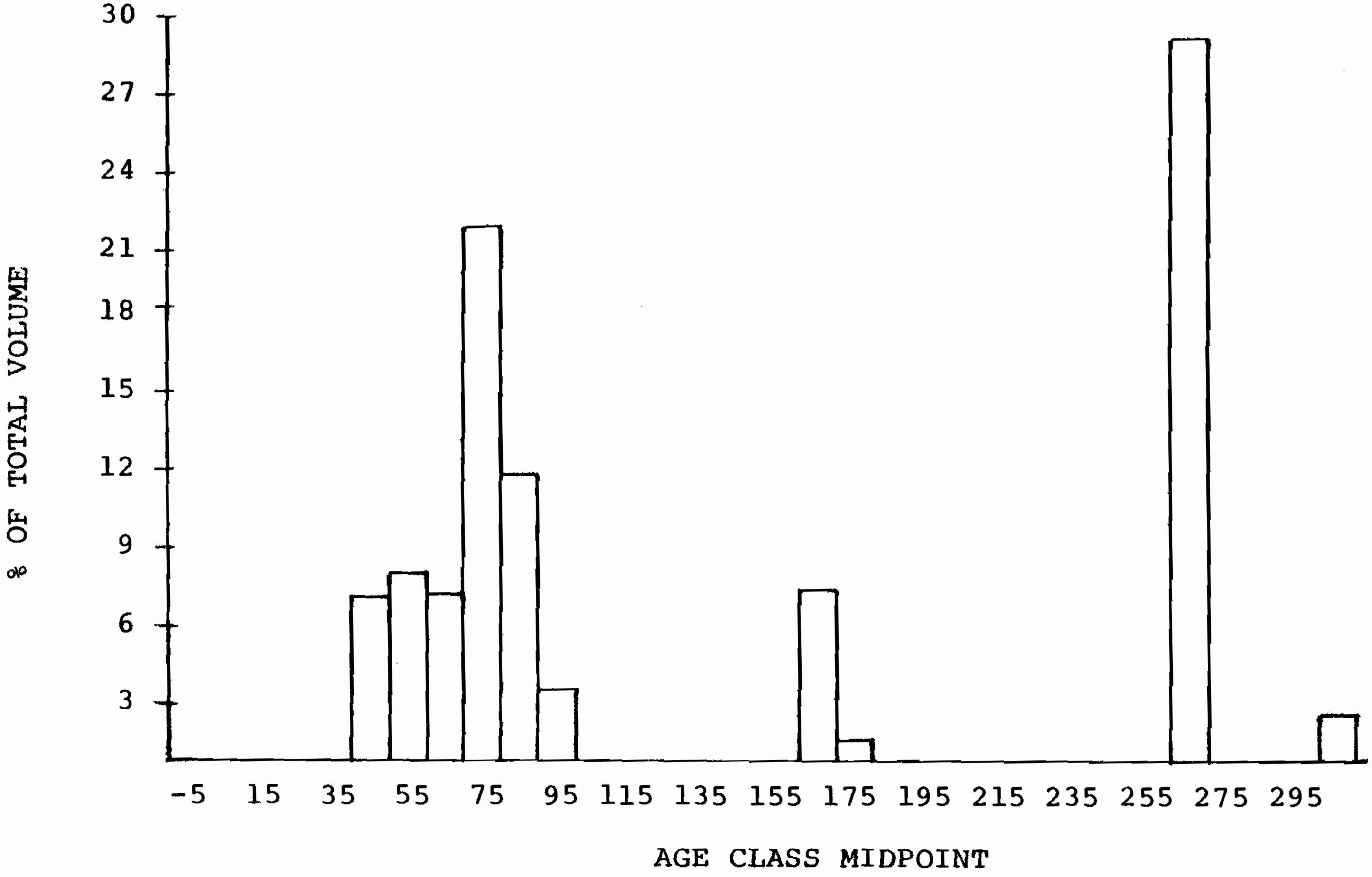
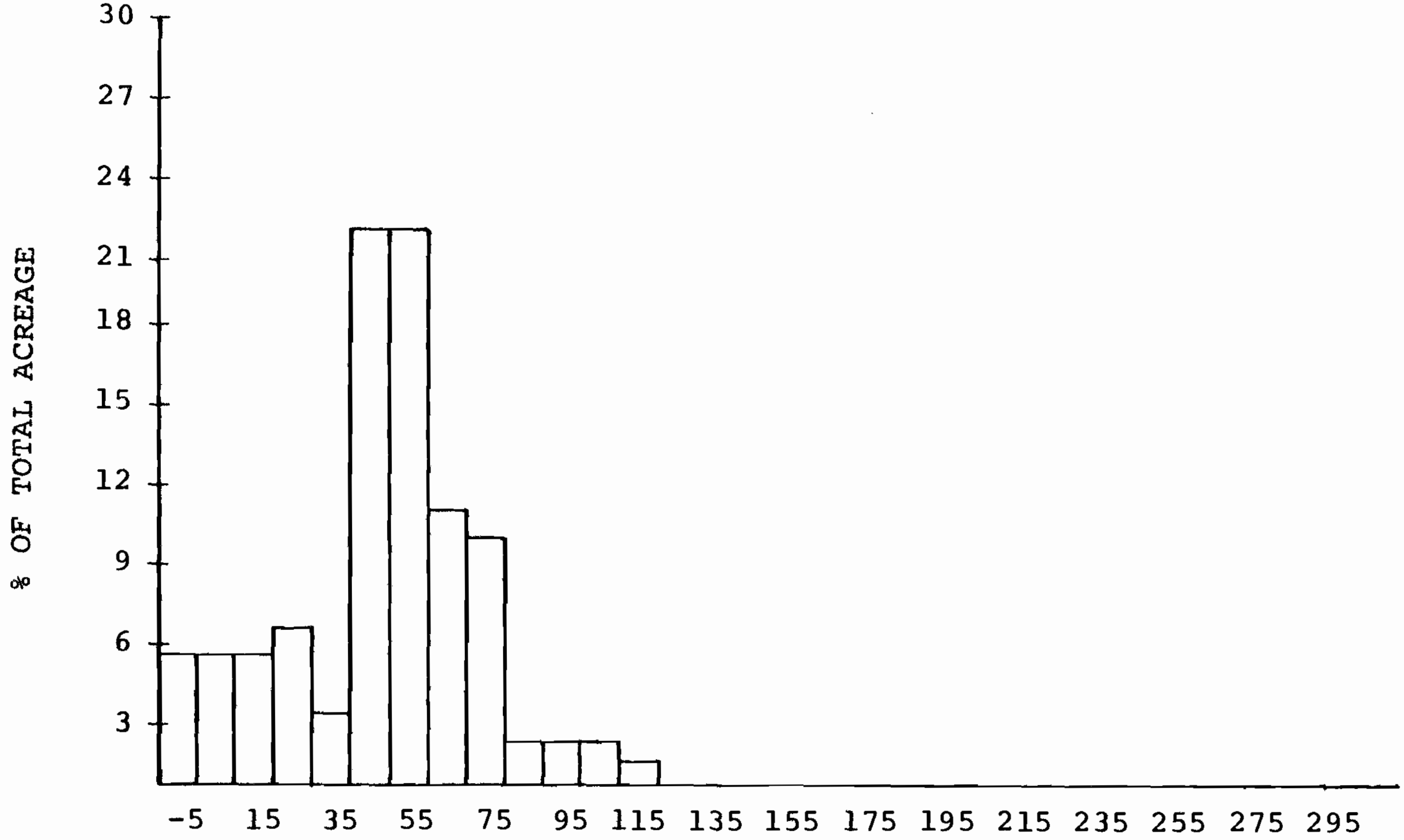


FIGURE 4I. INITIAL ACREAGE DISTRIBUTION

INVENTORY 5



AGE CLASS MIDPOINT

FIGURE 4J. INITIAL VOLUME DISTRIBUTION

INVENTORY 5

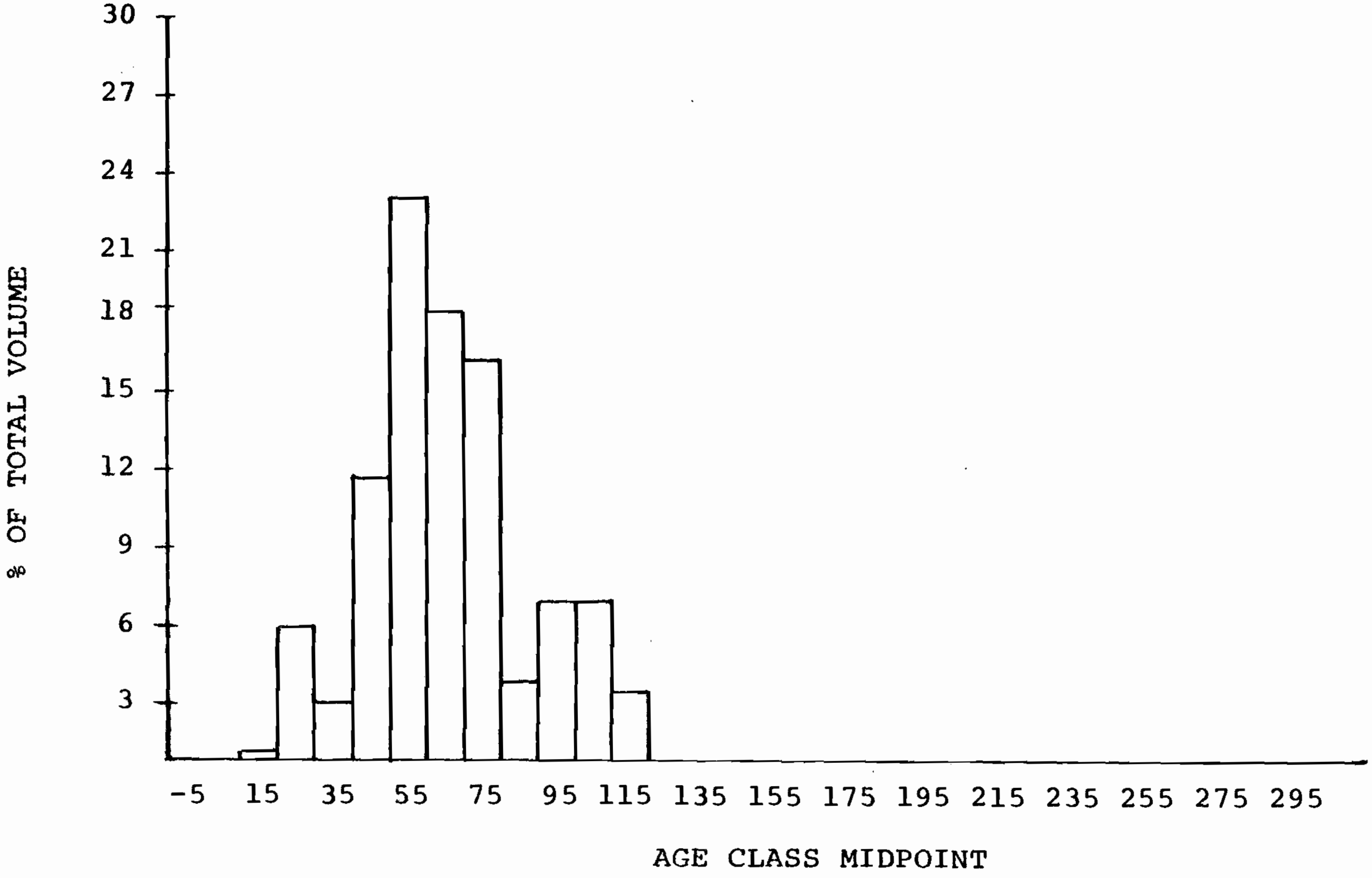


FIGURE 4K. INITIAL ACREAGE DISTRIBUTION

INVENTORY 6

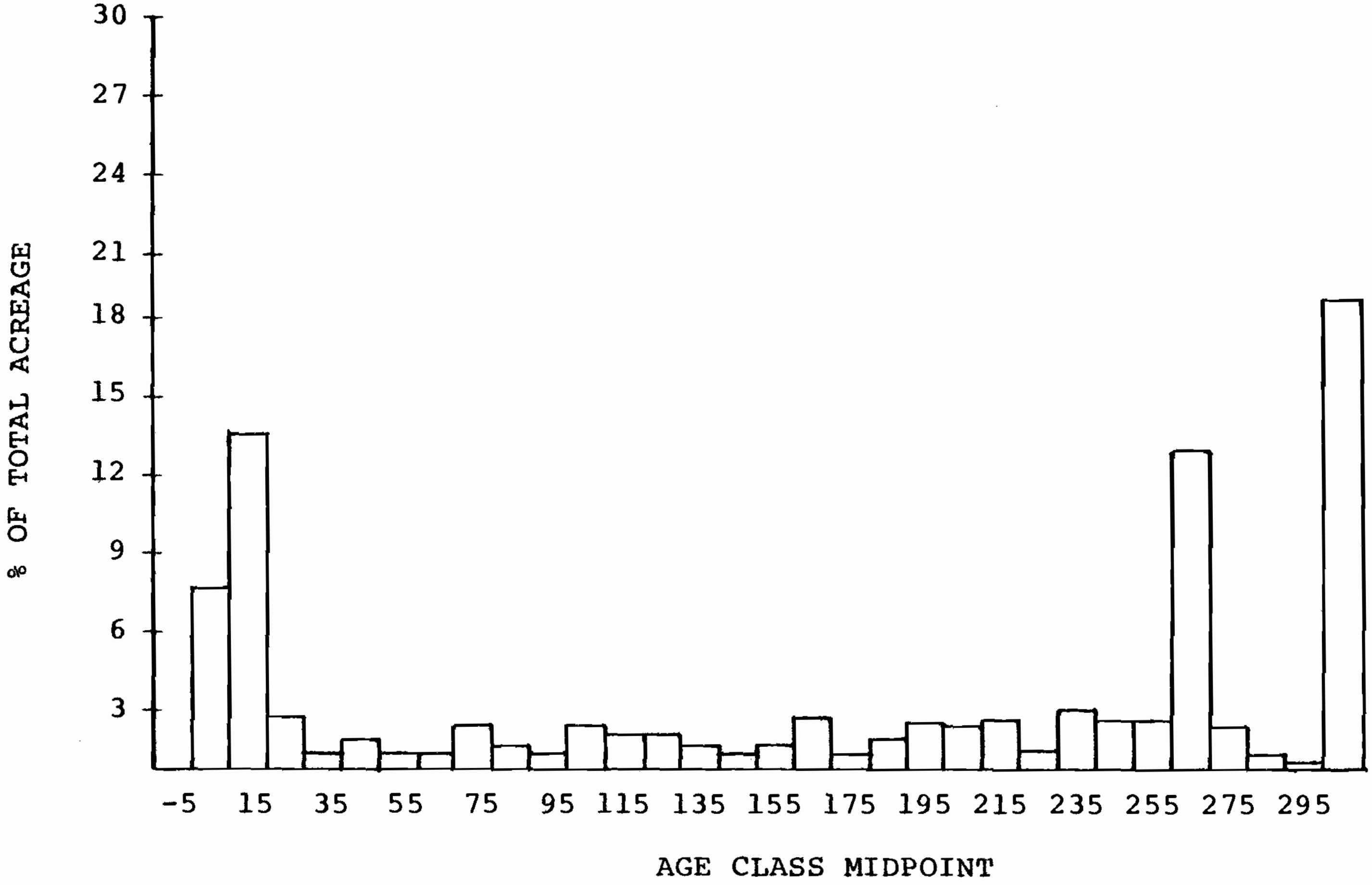


FIGURE 4L. INITIAL VOLUME DISTRIBUTION

INVENTORY 6

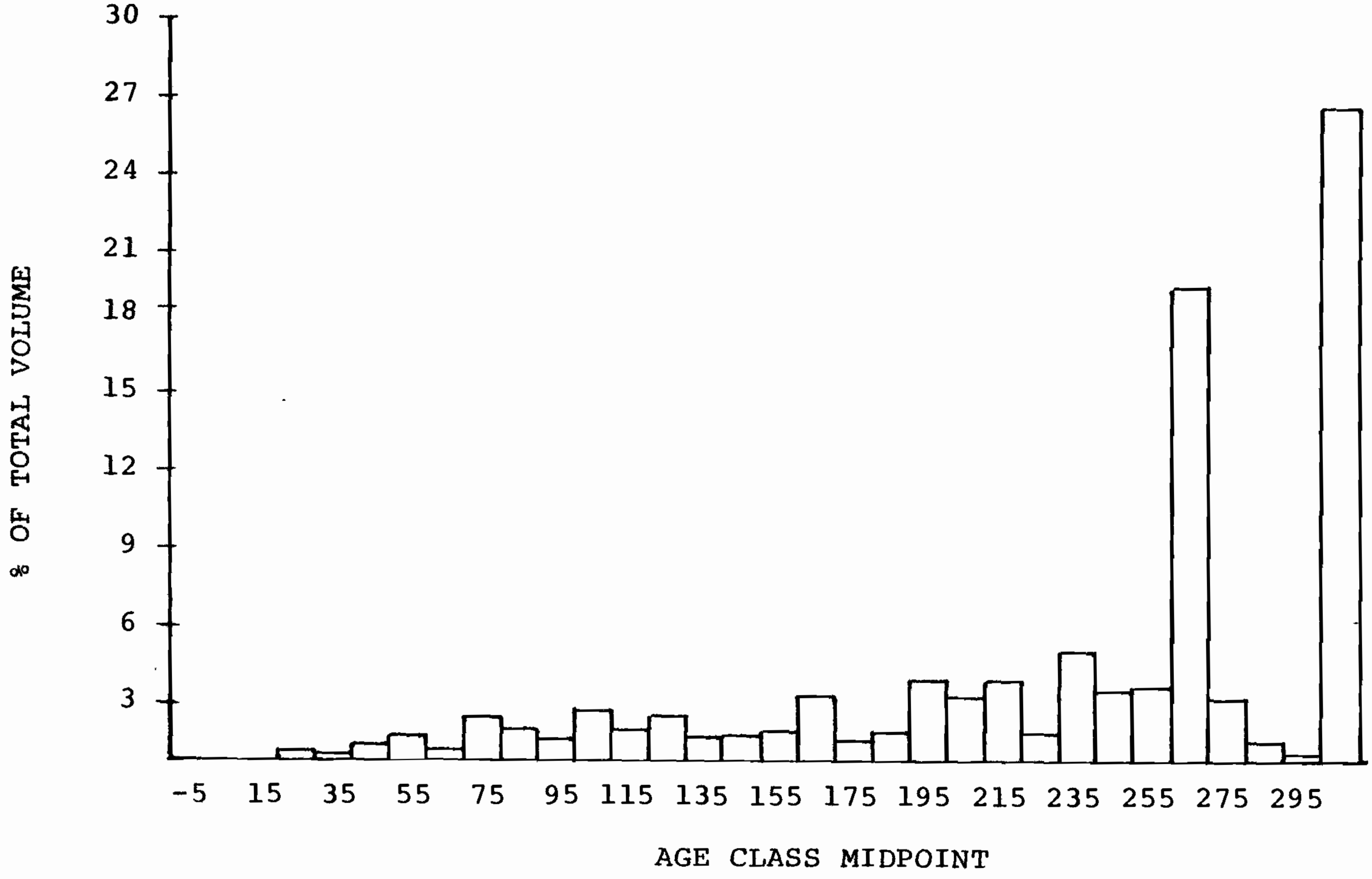


FIGURE 4M. INITIAL ACREAGE DISTRIBUTION

INVENTORY 7

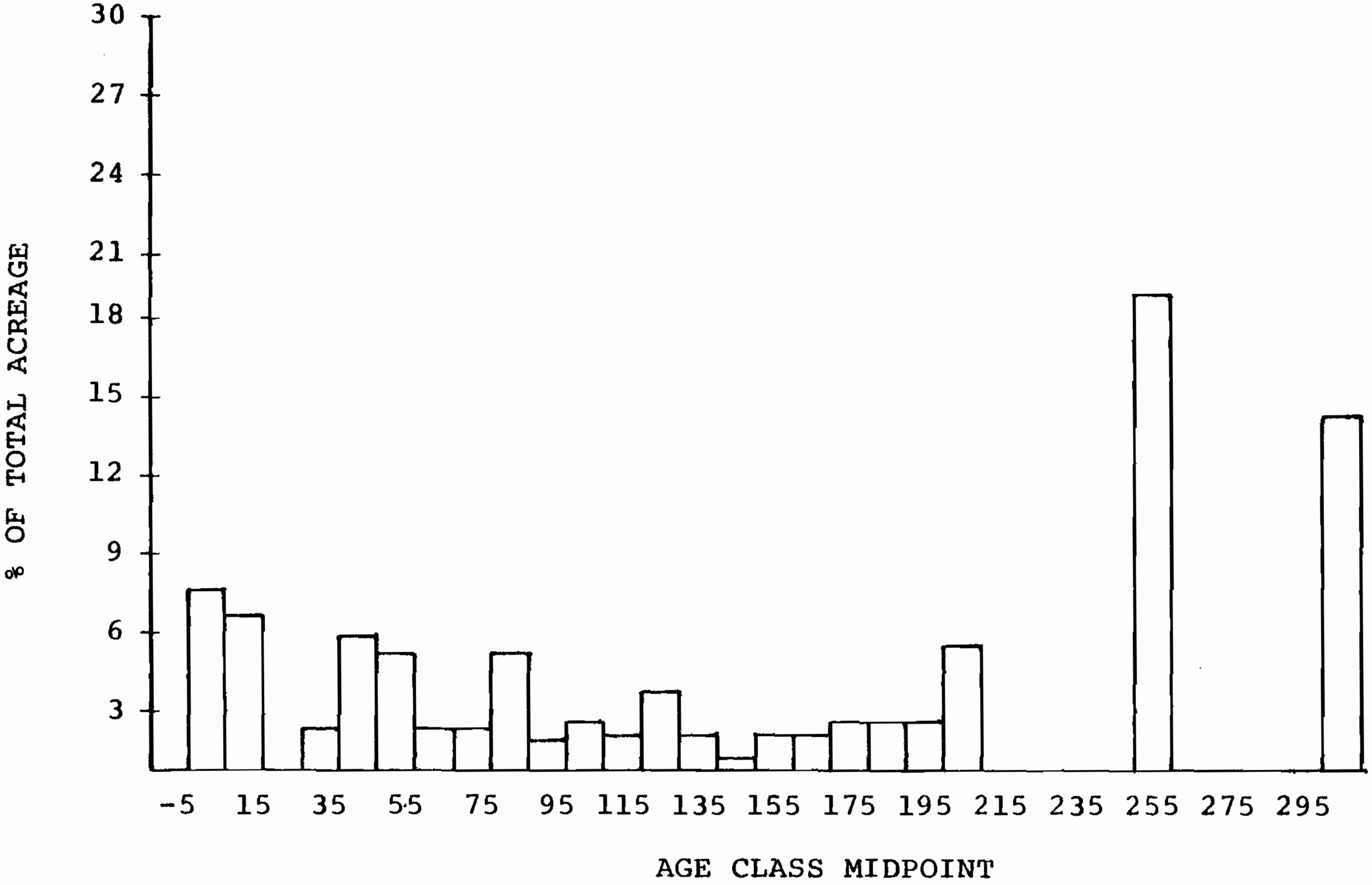


FIGURE 4N. INITIAL VOLUME DISTRIBUTION

INVENTORY 7

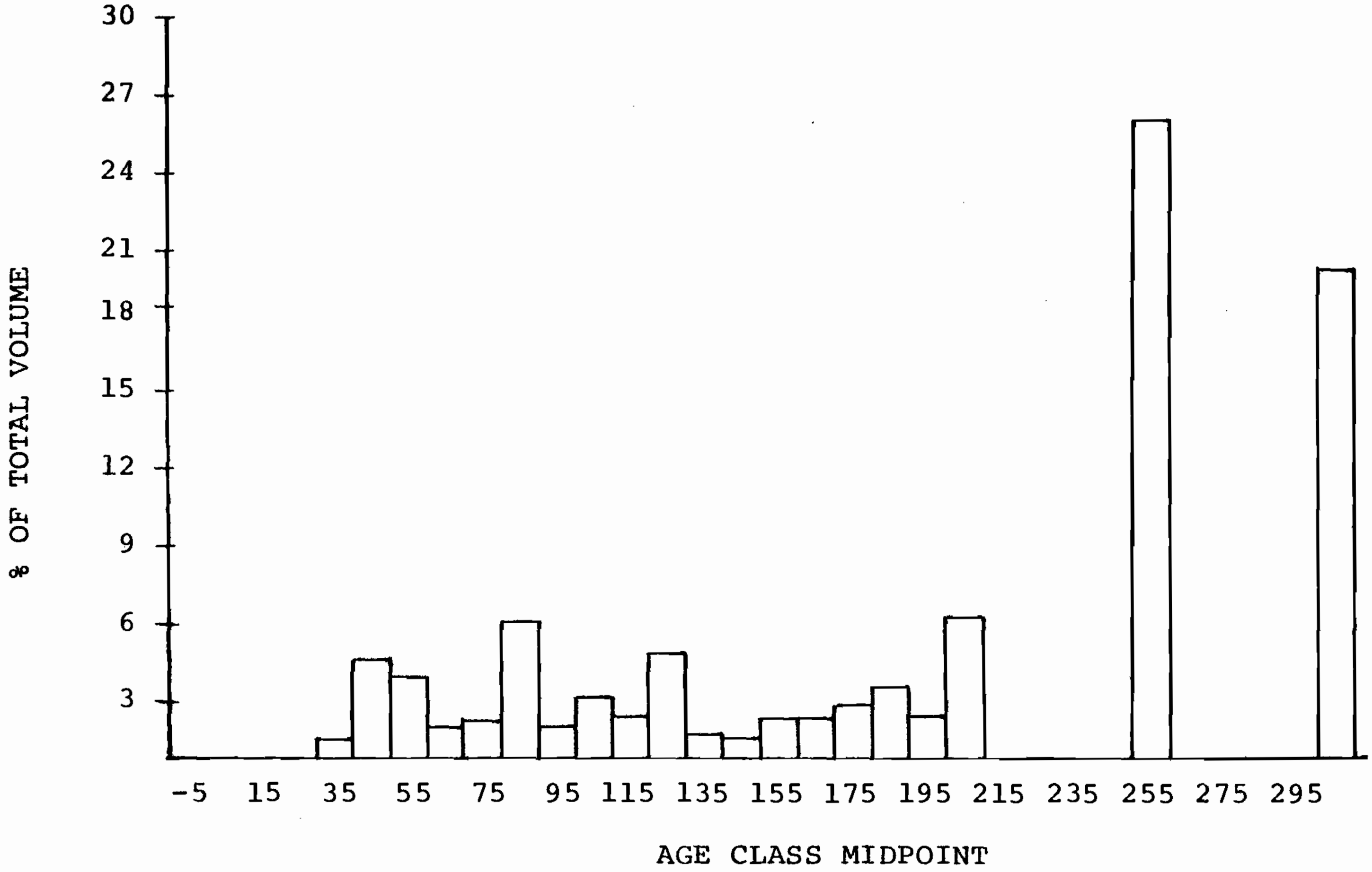


FIGURE 40. INITIAL ACREAGE DISTRIBUTION

INVENTORY 8

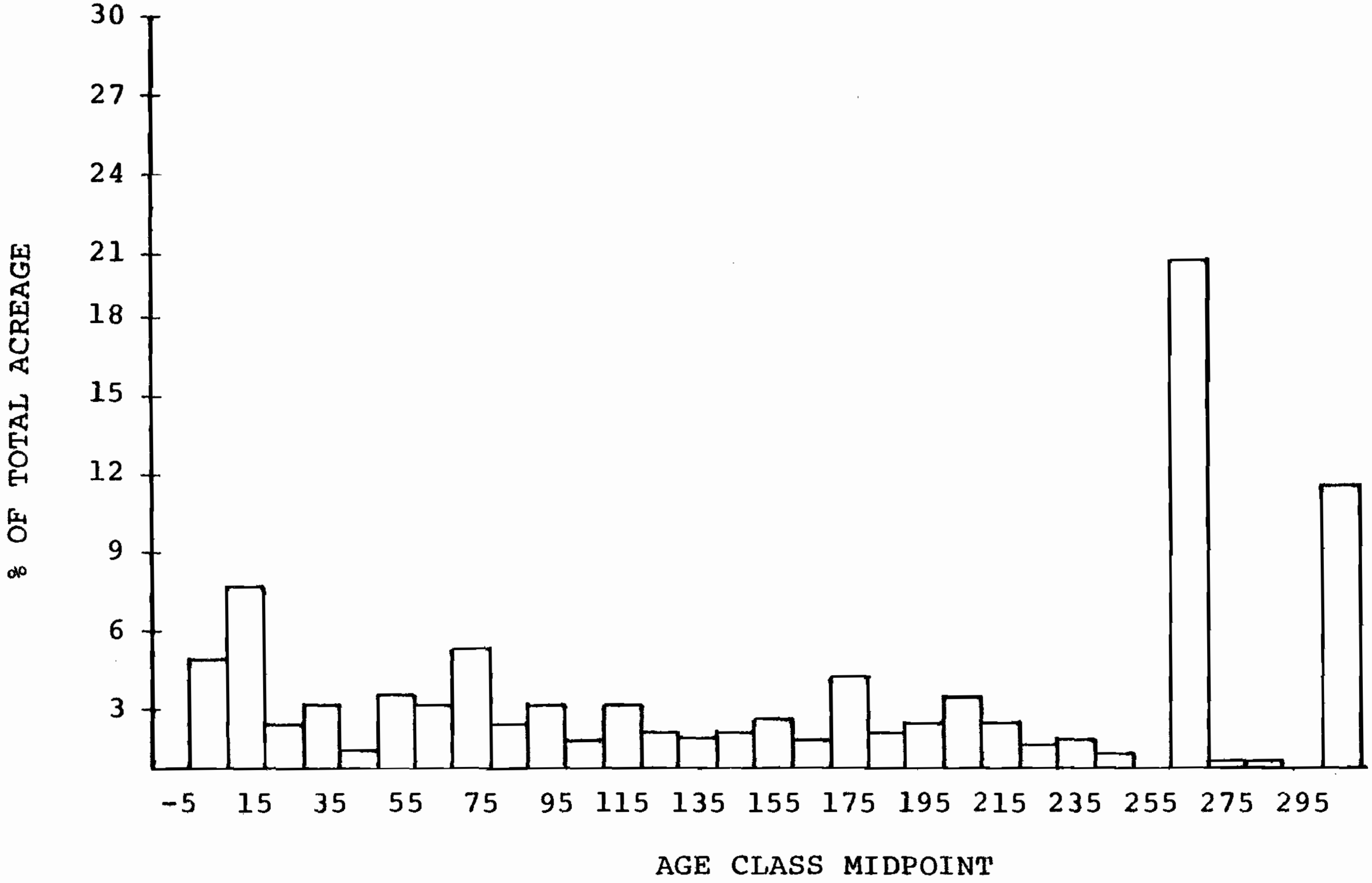
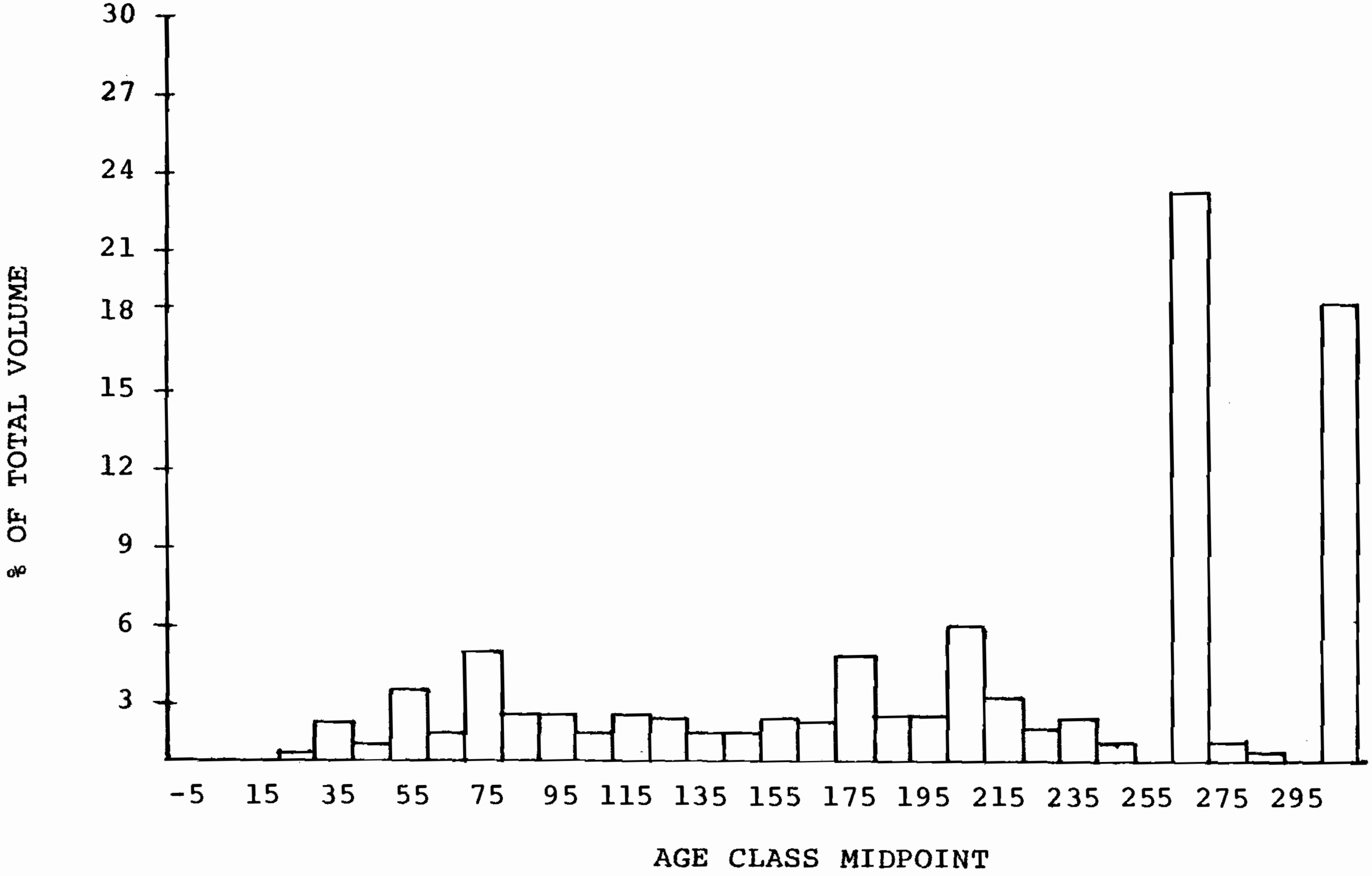


FIGURE 4P. INITIAL VOLUME DISTRIBUTION

INVENTORY 8



Inventory 2 - High site, wide range of age classes with small age class gaps, well - 41.3%, medium - 58.2%, poor - 0.5%, 233,007 acres, 2,121,113,874 cubic feet.

Inventory 3 - Low site, younger age classes with gap to one older age class, well - 36.7%, medium - 20.5%, poor - 42.8%, 21,319 acres, 58,589,250 cubic feet.

Inventory 4 - Medium site, range of ages with age class gaps, well - 39.5%, medium - 42.5%, poor - 18%, 37,550 acres, 154,381,027 cubic feet.

Inventory 5 - High site, younger age classes, well - 43.8%, medium - 29.3%, poor - 26.9%, 59,400 acres, 338,992,400 cubic feet.

Inventory 6 - Low site, all age classes, well - 50.8%, medium - 42.9%, poor - 6.3%, 263,605 acres, 1,619,013,004 cubic feet.

Inventory 7 - Medium site, range of age classes with gaps in the older ages, well - 12.2%, medium - 53.2%, poor - 34.6%, 109,934 acres, 703,191,140 cubic feet.

Inventory 8 - Low site, all age classes, well - 25.7%, medium - 47%, poor - 27.3%, 261,995 acres, 1,098,414,015 cubic feet.

A survey (Table 8) of forest inventory personnel indicated errors in volume per acre estimates were more likely than errors in acreage by age class estimates. Accordingly, the base inventories were adjusted to reflect those errors by

TABLE 8. SURVEY FORM

Inventory purpose	Age Class	Volume/acre Standard error %		No. of acres Standard error %		Confidence Level
		Target	Aver. achieved	Target	Aver. achieved	
Management planning (forest or district)	old growth					
Management planning (forest or district)	merchantable young growth					
Management planning (forest or district)	pre-merchantable	X	X			
Property appraisal for purchase	old growth					
Property appraisal for purchase	merchantable young growth					
Property appraisal for purchase	pre-merchantable	X	X			
Single stand appraisal (timber sale)	old growth					
Single stand appraisal (timber sale)	merchantable young growth					
X	X	% Stocked or No. trees/acre Standard error %		X	X	X
		Target	Aver. achieved			
Single plantation survey	pre-merchantable					

Check one:

Public agency ----

Private firm ----

increasing all volumes per acre by 20 percent, regardless of age class, stocking level, or inventory number and by decreasing all volumes per acre by 20 percent resulting in a total of eight base inventories and 16 adjusted ones. The extreme standard error response of 20 percent was used as the adjusting factor because it showed effects of the worst possible case. In fact, the worst possible case was probably exceeded by changing all volumes per acre in the same direction. In an operational inventory compensating errors would tend to make the overall initial volume estimate closer than 20 percent. The results will give forest managers a range or pseudo-confidence interval for the effects of inventory uncertainty.

After acquiring and standardizing the yield information and obtaining base and adjusted inventories, simulation combinations to be compared were established. With the exception of some extra simulations for Inventories 5, 6, and 7, the set of simulations is standard for all inventories and is shown in Table 9.

Three additional simulations per inventory were done using Inventories 5, 6, and 7, which represent a high site, a low site, and a medium site, respectively. These are shown at the bottom of Table 9. Two of these were done to test the effect of the approach to normal function on resulting harvest schedules. The third was done to test the

TABLE 9. SIMULATION COMPARISONS STANDARD TO ALL INVENTORIES

Base: Inventory X, Extensive Management, Bull. 201	Compared with:
1. Inv. X + 20%, Ext. Mgt., Bull. 201	Base
2. Inv. X - 20%, Ext. Mgt., Bull. 201	Base
3. Inv. X, Ext. Mgt., DFIT	Base
4. Inv. X, Ext. Mgt., DNR Empirical	Base
5. Inv. X, Ext. Mgt., Hoyer's Natural	Base
6. Inv. X, Ext. Mgt., Bull. 201 - 15%	Base
7. Inv. X, Int. Mgt., Bull. 201	Base
8. Inv. X, Int. Mgt., DFIT	3, 7
9. Inv. X - 20%, Int. Mgt., Bull. 201 - 15%	7
ADDITIONAL SIMULATIONS APPLIED TO INVENTORIES 5,6, and 7	
10. Inv. X, Ext. Mgt., Bull. 201 with DFIT App. to Normal	Base
11. Inv. X, Ext. Mgt., Hoyer's Natural with Bull. 201 App. to Normal	Base, 5
12. Inv. X, Ext. Mgt., Bull. 201 with constant site index, Inv. 5 - site 185, Inv. 6 - site 100, Inv. 7 - site 140.	Base

effect of holding site index constant across age classes. When comparing initial Bulletin 201 yields generated by the cubic yield equations of the TREES simulation model with the table values of the bulletin itself it was apparent that site index was changing from age class to age class. Site indexes for younger age classes were shown in Table 1. In the simulation to test for the effect of fixed site, yield values were taken directly from Bulletin 201, Table 2 (McArdle et al. 1930) and inserted into the TREES simulation model in yield table format.

One additional simulation was done on Inventory 5. The base inventory volumes per acre were decreased by ten percent, one half the 20 percent adjustment applied to test the impact of initial inventory errors. By comparing relative differences between the base and the 10 percent adjusted inventory simulation and between the base and the 20 percent adjusted inventory simulation an indication of the effect of the magnitude of initial inventory errors can be seen.

The TREES model was used as the computational tool in this study to generate all the harvest schedules. It is a comprehensive, yet flexible harvest scheduling simulation model developed at Oregon State University (Beuter et al. 1976). The model is thoroughly described in a recent publication (Tedder et al. 1980). TREES was used as the harvest scheduling model because its flexibility permitted standardizations and adjustments necessary to make comparisons on a ceteris paribus basis.

The harvest scheduling technique used in this study was the sequential maximum even-flow of volume method. This method, also known as the stairstep even-flow approach because of the appearance of the results when graphed, was first documented by Chappelle et al. (1968) in the SORAC model. This is a popular method because it will provide a relatively smooth transition in terms of harvest levels from the current forest structure to a regulated one while providing the flexibility necessary to maximize those levels while satisfying constraints. Because it is essentially a volume regulation technique it is especially useful in this study to demonstrate differences in harvest levels due to inventory or yield changes. The harvest level is allowed to vary from decade to decade, either up or down, in response to a changing forest inventory. No constraints were placed on how large the change from one period to the next could be, though this is an option occasionally used with this method.

Each period harvest is computed as if it were the first period in a strict even-flow of volume plan. The first decade harvest level is calculated as the maximum volume that is sustainable for a specified number of periods while ensuring the ending condition constraint, checked after harvest in the last period, is satisfied. The sustainability period, also known as the inner cycle, was set as seven periods for all simulations, i.e., the first period plus six additional periods. It was set as seven because that is generally the length of a rotation for Douglas-fir. Changing the inner cycle length would affect the harvest levels but the change would be in the same direction for all simulations, higher harvests if it was shortened and lower levels if it was lengthened.

After the first period harvest is established it is simulated, the resulting inventory is grown to the second period, and the process is repeated. The whole procedure is repeated until a harvest is established for each period in the planning horizon. The planning horizon was selected to be 13 decades because that seemed to be the minimum length of time necessary for the sample forests to achieve an approximate equilibrium, i.e., for a long-run sustained yield to be established. Changing this length would not affect harvest levels.

The ending condition constraint is imposed on the inventory after the simulated cut is made for the last period in the inner cycle, the seventh. The constraints were that all volume within a tolerance level in age classes above 75 years old had to be harvested by the time of that last cut but not more than the tolerance level amount could be cut from the 75 year age class itself. This condition eventually results in a rotation age of 75 years for most stands. This was arbitrarily established as the desired rotation age but it is in the range of ages normally suggested for Douglas-fir rotations. The tolerance level used was one percent of the trial periodic harvest level. If the ending condition was not satisfied the initial trial harvest level would be changed and the process would begin anew.

An attempt was made to choose realistic values for assumptions concerning regeneration lag time, regeneration success levels, amount of mortality salvage, and the proportion of land that moves into the commercial and precommercial regimes for intensive management. These assumptions were standardized across all the yield and inventory combinations so they should not affect any of the results, with one exception.

The exception is extensive management regimes vs. intensive management regimes where those assumptions play a vital part in establishing the differences. As noted by Johnson et al. (1975) several factors above and beyond the increased growth rates suggested by the yield predictor contribute to the higher yields of intensive management. These include shorter regeneration lags, better stocking densities after regeneration, less unsalvaged mortality, and a faster rate of rehabilitation of non-stocked land. Because of the role of these assumptions in the extensive vs. intensive management comparisons, they are shown in Table 10.

TABLE 10. MANAGEMENT ASSUMPTIONS

	Assumption	Extensive Management	Intensive Management W/C.T.[1]	Intensive Management W/P.C.T.[2]
1.	Regeneration lag	2(3)[3] yrs.	2 yrs.	2 yrs.
2.	% cutover acres to unstocked	3(4)%	2(3)%	2%
3.	% cutover acres to well stocked	55(50)%	65(60)%	85(80)%
4.	% cutover acres to medium stocking	30%	25%	10%
5.	% cutover acres to poor stocking	15(20)%	10(15)%	5(10)%
6.	% mortality available for salvage	50%	75%	75%
7.	Minimum mortality volume/acre to permit salvage	800 cu.ft.	800 cu.ft.	800 cu.ft.
8.	% of regenerated acres to Extensive Management in first 50 years	100%	10%	
9.	% of regenerated acres to Extensive Management after year 50	100%	5%	
10.	% of regenerated acres to C.T. regime in first 50 years	0%	30%	
11.	% of regenerated acres to C.T. regime after year 50	0%	20%	
12.	% of regenerated acres to P.C.T. regime in first 50 years	0%	60%	
13.	% of regenerated acres to P.C.T. regime after year 50	0%	75%	

[1] Commercial thinning

[2] Precommercial thinning

[3] Low site value when different

IV. RESULTS and DISCUSSION

Base harvest schedules for each unadjusted inventory using Bulletin 201 yields for extensive management are shown in Figures 5A to 5H. Absolute harvest levels shown in millions of cubic feet per decade demonstrate the pattern of fluctuation by decade of each base schedule and the magnitude of harvests being evaluated in this study. Note the vertical scale is different on each figure.

A forest manager would be most interested in the first decade harvest levels because those would be implemented in the field. An annual target level would be established by dividing the first decade level by ten. Actual yearly harvests would then fluctuate around this target because of market conditions, cash flow needs, weather conditions, and logistical constraints.

As evidenced by small fluctuations in harvest levels for the last few decades of the planning horizons, all base schedules are, with the possible exception of the one for Inventory 3, approaching the equilibrium condition of a long-run sustained yield harvest level. Apparently, none have rigidly achieved it as evidenced by those fluctuations. Additional evidence for the conclusion that the planning horizon needed to be slightly longer for a long-run sustained yield to be achieved can be found in percent last

FIGURE 5A. BASE HARVEST SCHEDULE
INVENTORY 1 BULLETIN 201 YIELDS

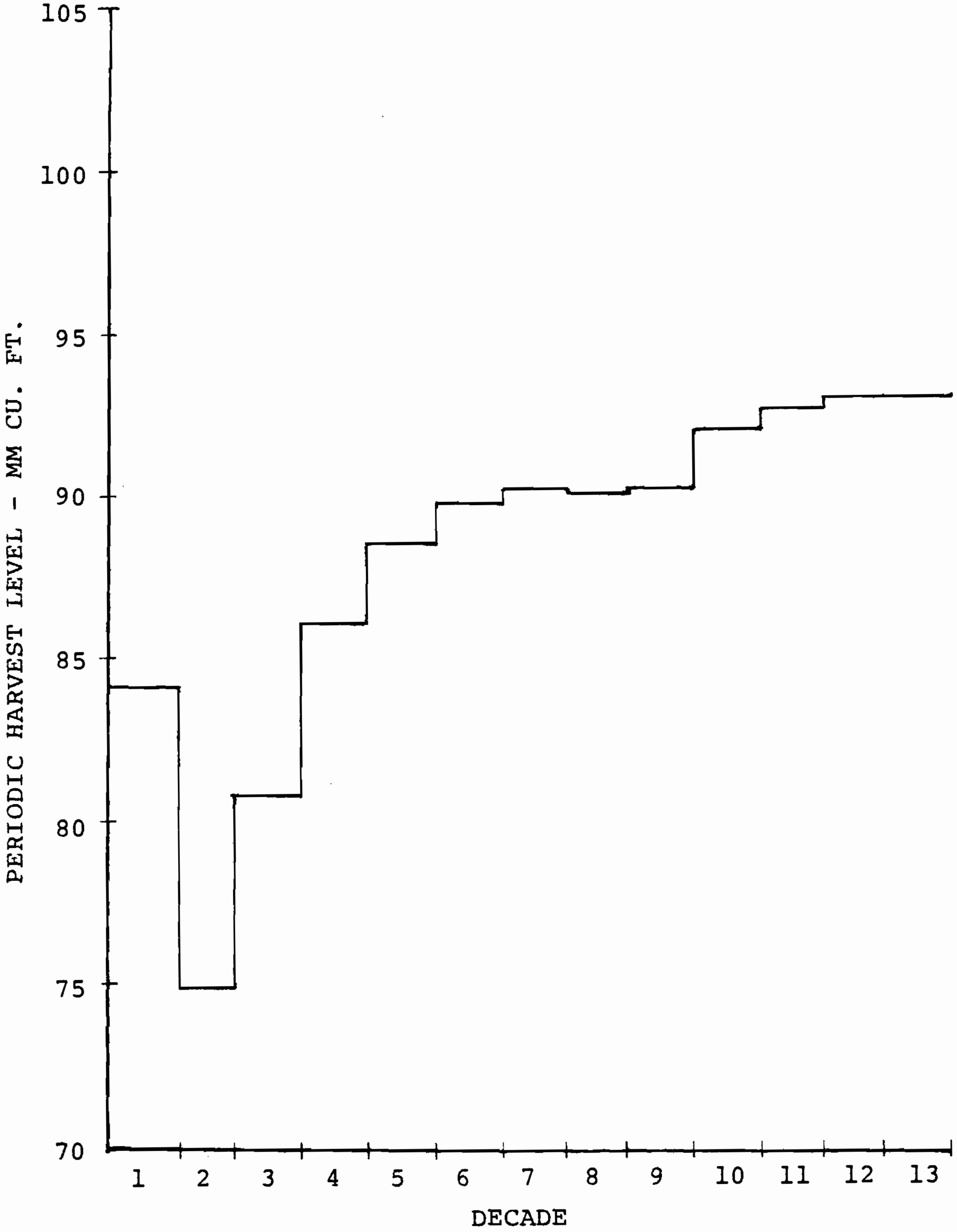


FIGURE 5B. BASE HARVEST SCHEDULE

INVENTORY 2 BULLETIN 201 YIELDS

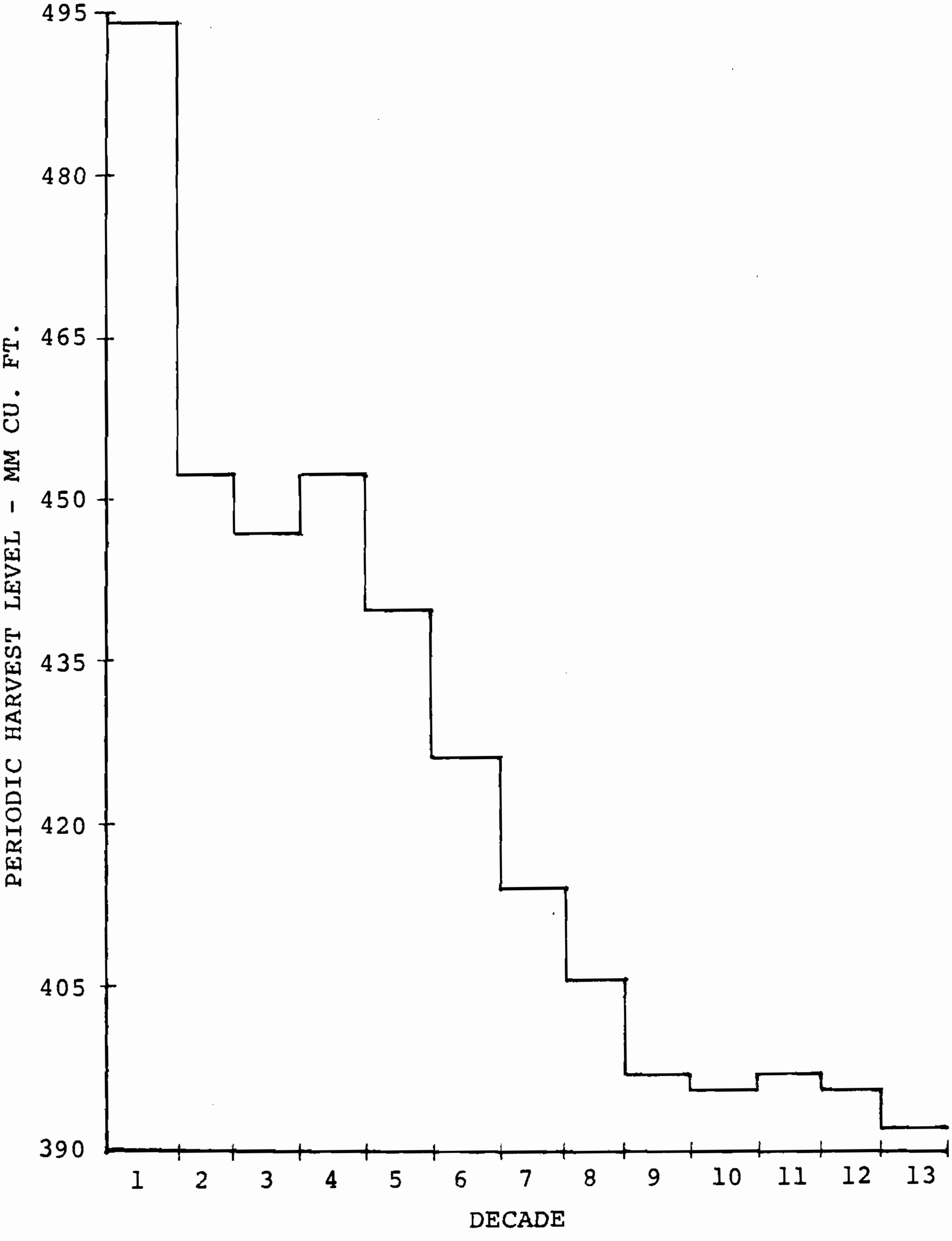


FIGURE 5C. BASE HARVEST SCHEDULE
INVENTORY 3 BULLETIN 201 YIELDS

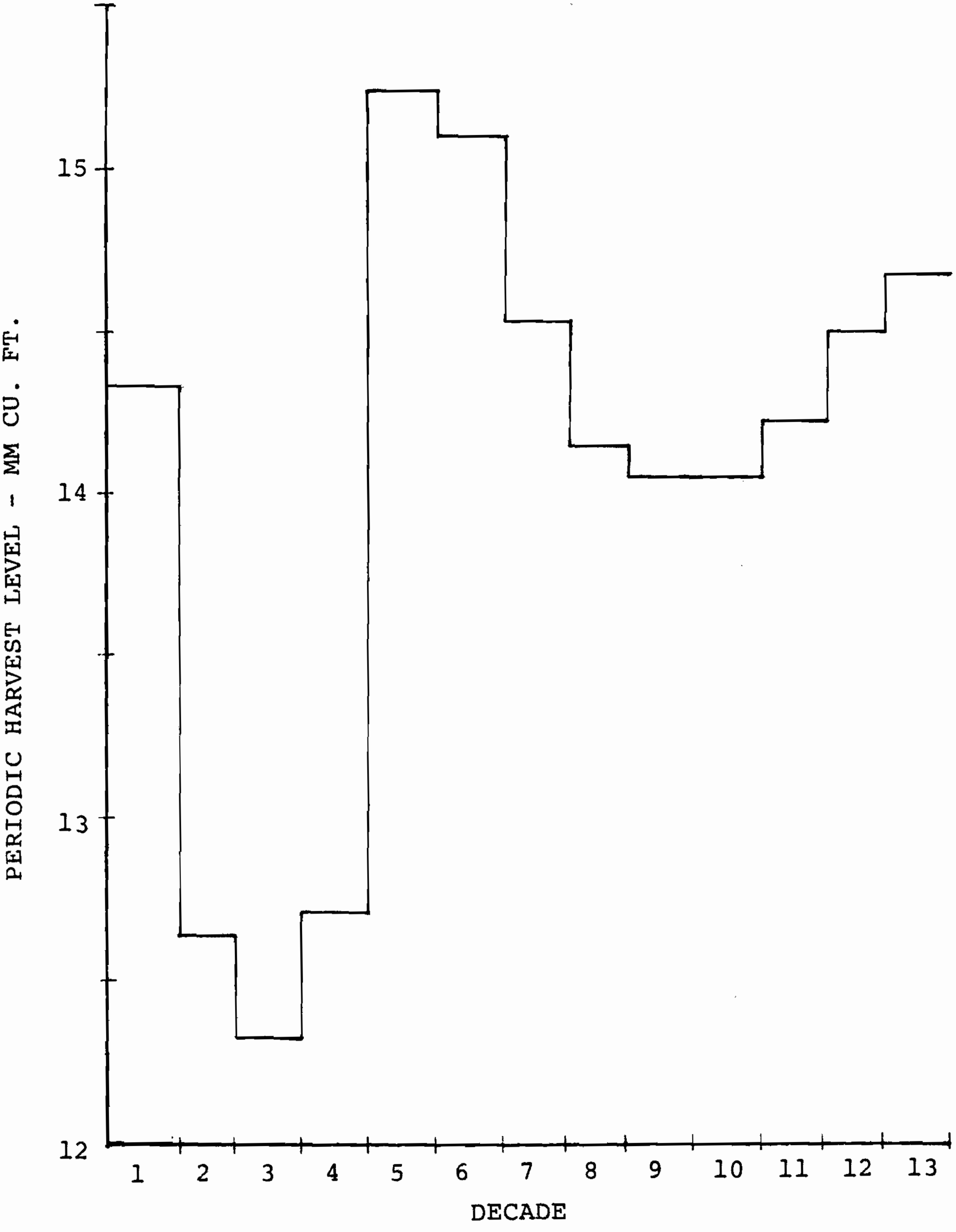


FIGURE 5D. BASE HARVEST SCHEDULE

INVENTORY 4 BULLETIN 201 YIELDS

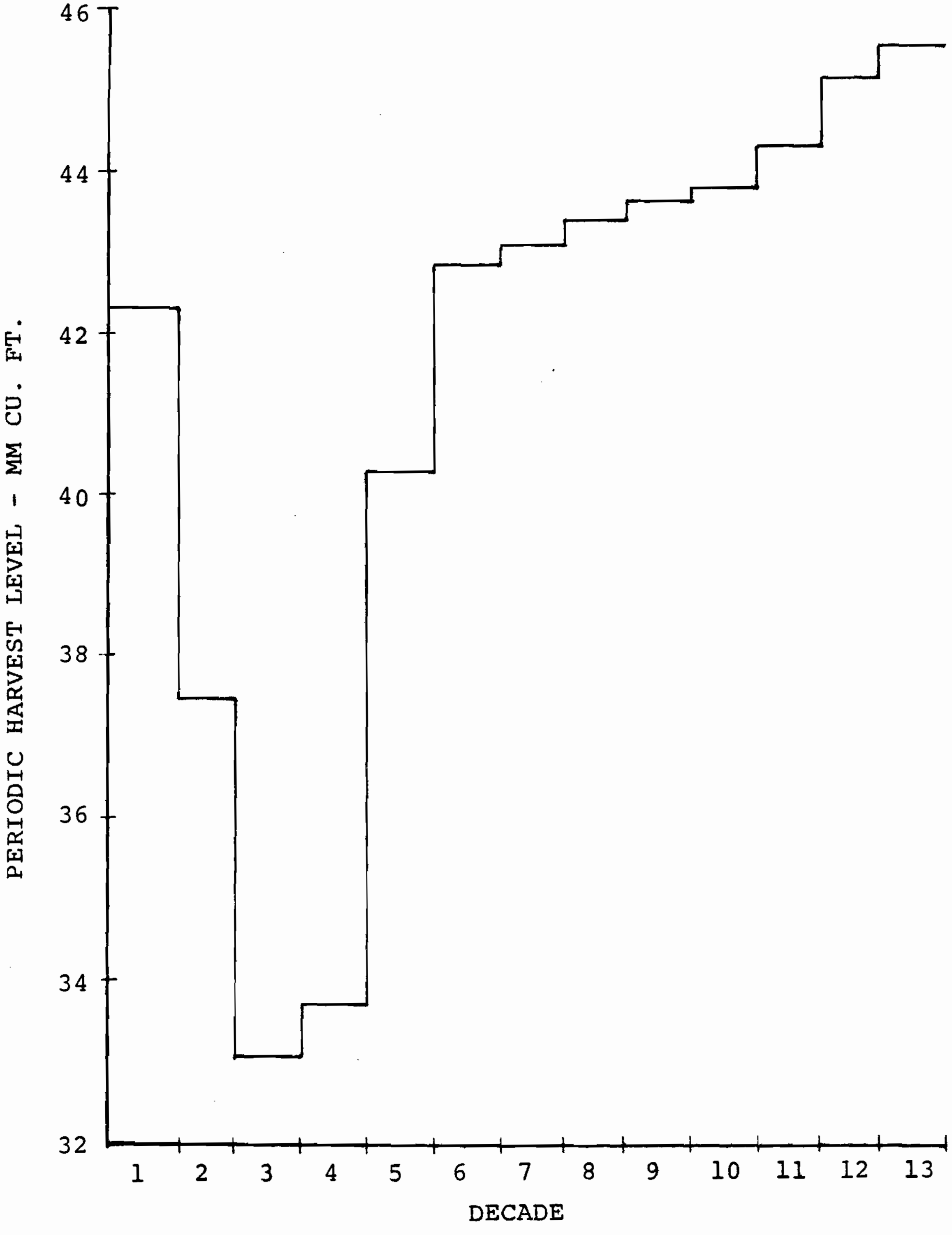


FIGURE 5E. BASE HARVEST SCHEDULE

INVENTORY 5 BULLETIN 201 YIELDS

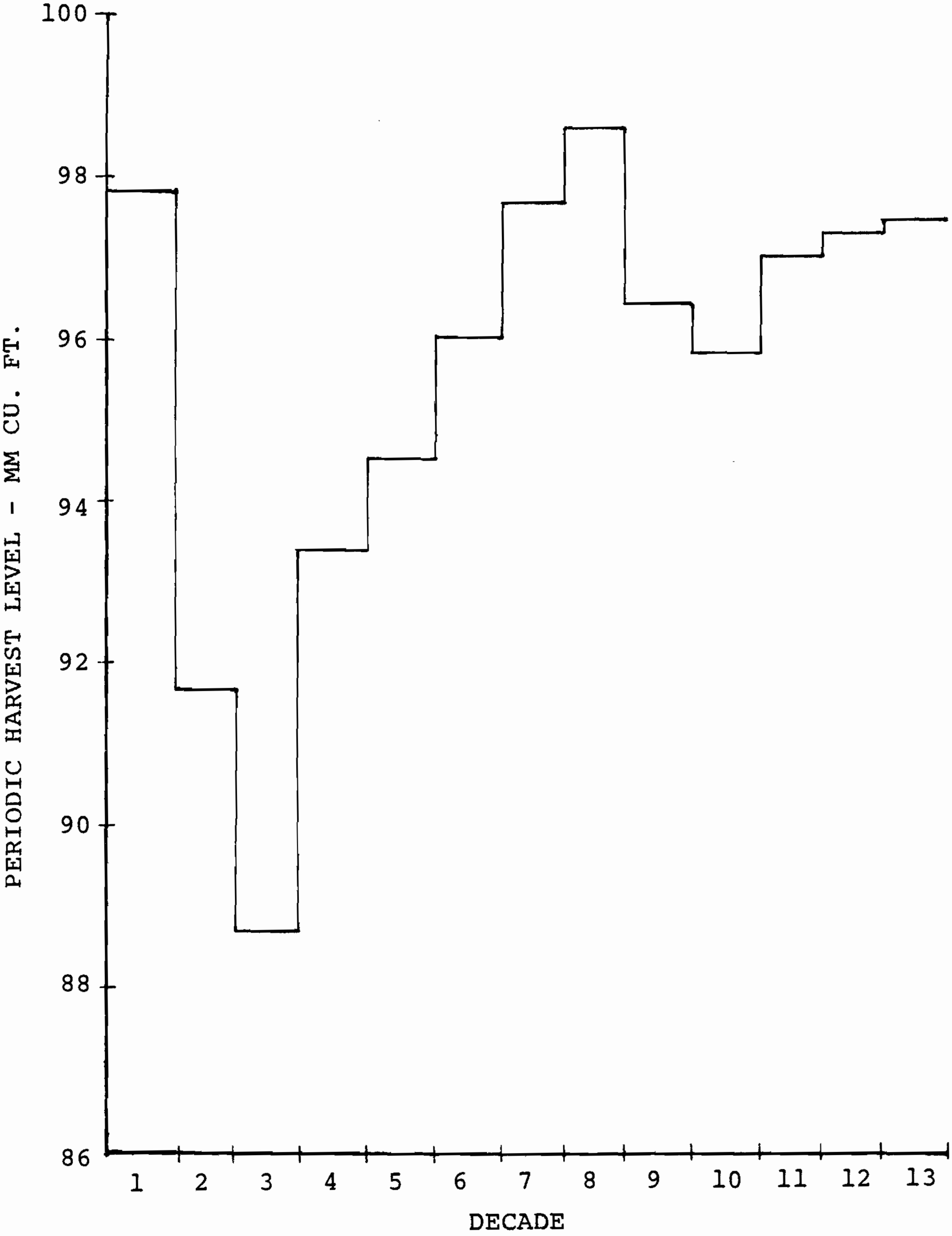


FIGURE 5F. BASE HARVEST SCHEDULE

INVENTORY 6 BULLETIN 201 YIELDS

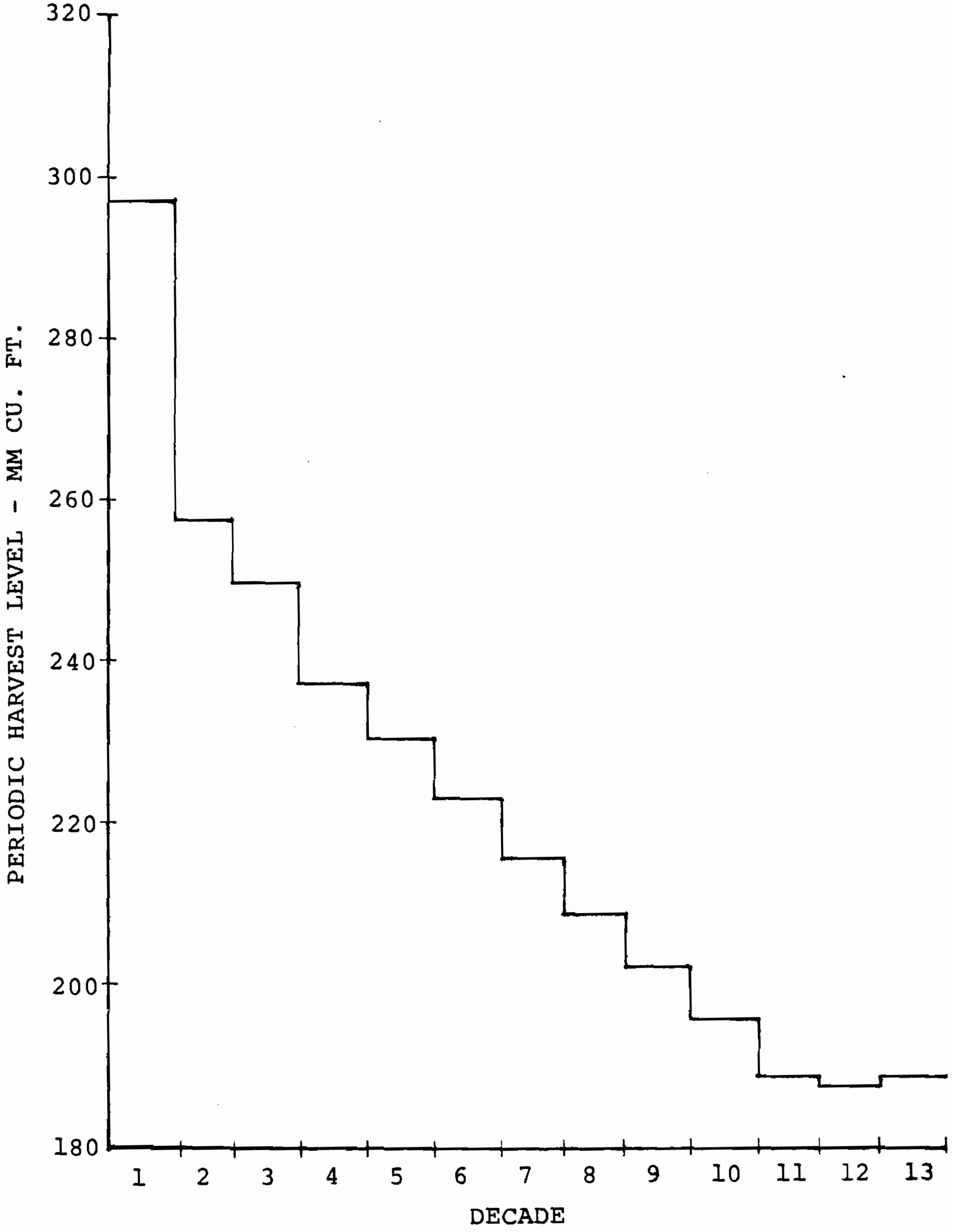


FIGURE 5G. BASE HARVEST SCHEDULE

INVENTORY 7 BULLETIN 201 YIELDS

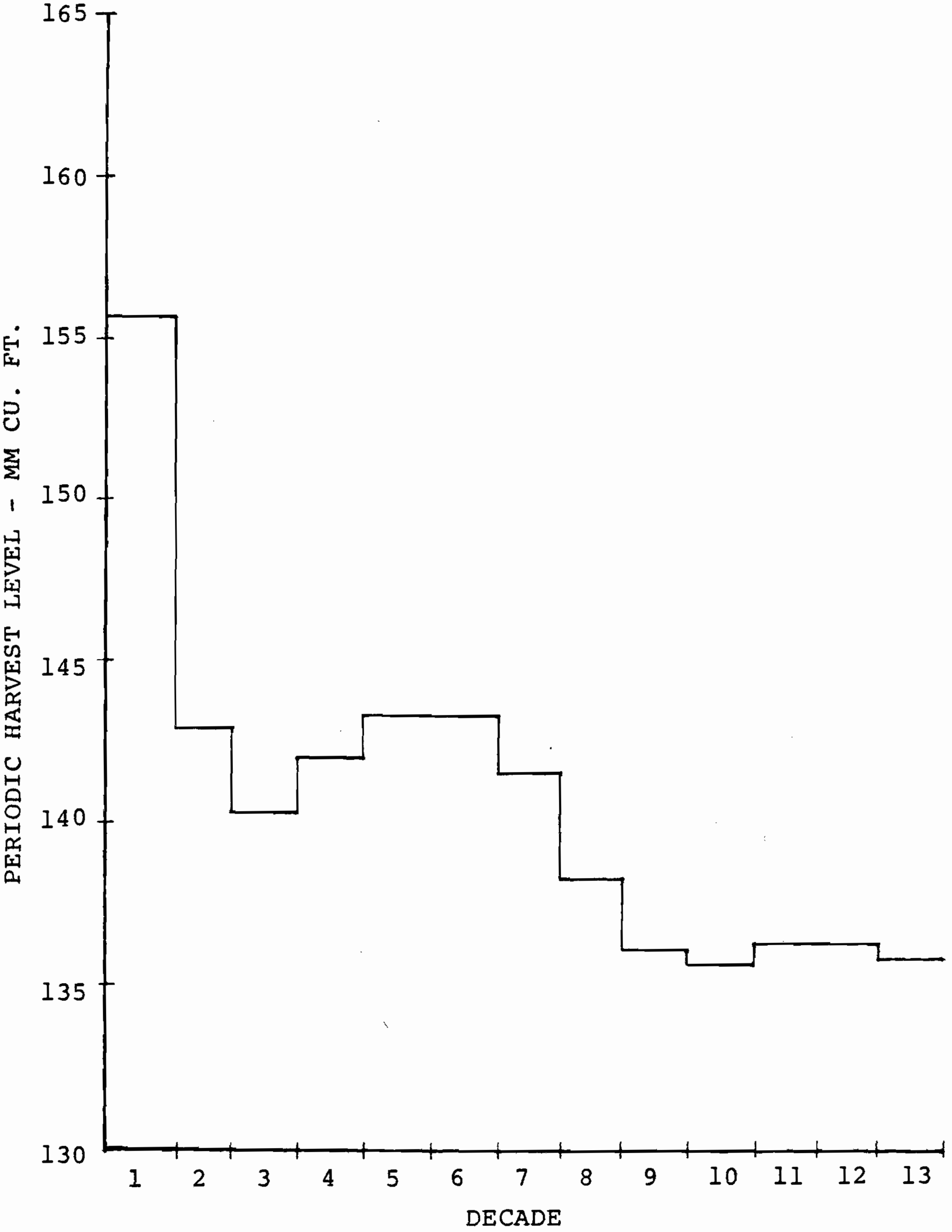
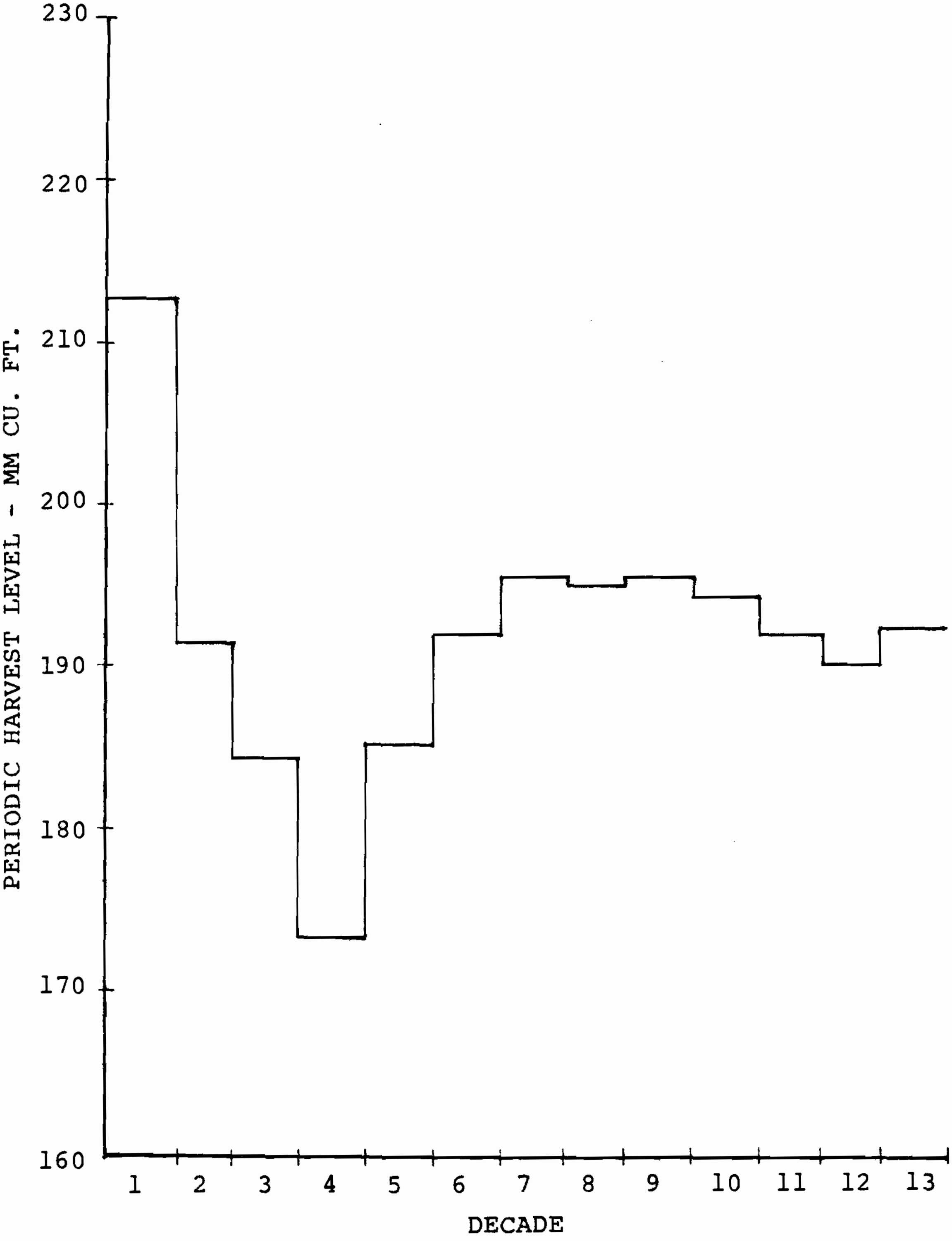


FIGURE 5H. BASE HARVEST SCHEDULE

INVENTORY 8 BULLETIN 201 YIELDS



decade harvest level differences for comparisons using adjusted inventories. These differences are shown in Tables 11A and 11B. Because yields and other assumptions are the same, long-run sustained yields should also be equal, i.e., percent differences should equal zero. The differences, though small ranging from 1.8 percent to -2.0 percent, do not equal zero.

Each base harvest schedule can be categorized into one of two classes based on the fluctuation pattern of harvests. Harvest schedules for Inventories 1, 3, 4, 5, and 8 show a high initial cut followed by a sharp decline for a decade or two. That is followed by a long period of rising harvest levels eventually equalling or surpassing first period levels. Harvests for Inventories 2, 6, and 7 show the same high levels for the first period followed by a downward trend that continues until a gradual leveling off occurs late in the planning horizon. Each harvest schedule pattern can be explained by age class and stocking level distributions of initial inventories as described in the previous chapter and shown in Figures 4A to 4P.

In all cases, initially high first period cuts are caused by a liquidation of over-rotation-age stands, i.e., old-growth. The decline and gradual rise, as described for the first class of harvest schedules, is a result of insufficient acreage in younger age classes combined with

TABLE 11A. PERCENT DIFFERENCES: BASE VS. INVENTORY X + 20%

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	13.6	1.3	5.4	A1
2	13.9	1.7	6.8	A2
3	15.0	1.2	6.9	A3
4	13.3	0.9	5.4	A4
5	14.4	1.4	6.6	A5
6	17.1	1.8	9.7	A6
7	15.1	1.6	6.9	A7
8	14.1	1.0	6.9	A8

TABLE 11B. PERCENT DIFFERENCES: BASE VS. INVENTORY X - 20%

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	-14.2	-1.2	-5.8	A1
2	-14.8	-1.6	-7.1	A2
3	-15.4	-1.4	-7.0	A3
4	-13.5	-1.0	-5.5	A4
5	-14.5	-1.3	-6.6	A5
5(-10%)	- 7.3	-0.7	-3.3	A5
6	-17.5	-2.0	-9.7	A6
7	-15.4	-1.6	-7.0	A7
8	-15.4	-1.3	-7.2	A8

poor stocking levels. Except for the small old-growth components, these forests are initially understocked. Harvest levels rise only after stocking levels and younger age class acreage improve. The other three sample forests are overstocked initially with a large old-growth component that can be metered out over a longer period of time, diffusing effects of age class gaps occurring in younger ages. In addition, overall stocking levels on Inventories 2, 6, and 7 are better than on the others. Particular patterns for each harvest schedule are dependent on the size of the old-growth component, ages of missing or deficient age classes, especially younger ones, and initial stocking levels.

Relative differences in percent between comparable periodic harvest levels is the measurement unit used to evaluate results. Absolute differences are important to a forester charged with planning a harvest for an actual forest but are unique to the initial inventory characteristics. Those used in this study don't reflect an actual field situation faced by a forest manager so absolute differences won't be identified.

Relative differences are important because they reflect a general trend or range of effects due to uncertainty in inventory and yield information. A relative difference is easily computed as follows:

$$\% \text{ Rel. Diff.} = \frac{X_{2i} - X_{1i}}{X_{1i}} (100)$$

where X_{1i} = Harvest volume for the i^{th} decade of the harvest schedule serving as the standard.

X_{2i} = Harvest volume for the i^{th} decade of the harvest schedule being compared to the standard.

The harvest schedules previously referred to as Base, developed using unadjusted inventories with Bulletin 201 yields for extensive management, serve as the standards in all comparisons in which they are used. For comparisons not involving a Base, the one listed first in a table or figure heading is the standard.

Relative differences for first decade, last decade, and total plannning horizon harvests are shown in Tables 11A to 11N. Relative differences on a period by period basis are graphed in Figures A1 to A46 of the Appendix. These demonstrate the change in relative differences over time. Tables 11A to 11N serve as an index for the figures. While these tables and figures show relative differences between a simulation and a standard, they can also be used as an indication of the relative differences between two simulations when they are compared to the same standard. For example, a harvest schedule developed using DFIT can be compared to one generated with DNR Empirical Yields by comparing the results of each versus a common standard, the Base for the appropriate inventory. This is not done in this discussion.

As previously indicated, first decade results have the most significance because of the immediacy of implementation whereas future harvest levels would probably be adjusted several times before their implementation. Future harvests, including long-run sustained yield approximated here by last decade harvest levels, are important because long-run strategic planning involving capital investment in land and facilities is partly dependent on those projections. In addition, some harvest scheduling techniques link a periodic cut to what happens in future period harvests, giving those future harvests more immediate importance. The unconstrained sequential even-flow technique used in this study does that internally with the inner cycle sustainability time frame but once a period harvest is established it is not influenced by future harvests.

Relative long-run sustained yield differences can be interpreted as long-run equilibrium growth per acre per year differences as predicted by the different yield models given the assumptions used in the harvest model. Relative differences for total harvest over a planning horizon are shown because of their importance in strategic planning and because they reflect the average of the changing differences as shown in Figures A1 to A46.

As an example of interpretation of percent differences examine the results for Inventory 1 in Table 11A. Assume the Base is the harvest schedule that would be developed under perfect knowledge of the forest condition. A forester who mistakenly thought the inventory volumes per acre were 20 percent larger than the actual situation would plan for a first decade harvest 13.6 percent too large. In this case, the long-run sustained yield should be equal to the one calculated under perfect knowledge though this result shows a 1.3 percent overcut planned for decade 13. Anticipated harvests for the planning horizon are 5.4 percent higher than a plan made with perfect inventory knowledge. All this assumes only the inventory is uncertain and all other assumptions about the future are correctly identified. This overcutting could lead to an undesirable age class distribution and to a compensating, unexpected reduction in harvests when better information becomes available.

Contrary to overcutting, the results for Inventory 1 in Table 11B show a planned first decade cut 14.2 percent smaller than would be planned if the forester knew inventory volumes per acre were 20 percent larger than the data showed them to be. This represents a lost opportunity, an under utilization of available resources. The last decade harvest shows an undercut of only 1.2 percent and projected planning horizon timber harvest is 5.8 percent less than would be projected with perfect knowledge. Figure A1 in the Appendix shows the overcutting and undercutting for the first and last decades of these two cases plus the gradual transition of relative differences between them.

Results of the inventory error trials are shown in Tables 11A and 11B and Figures A1 to A8. The inventory adjustments did not change the age class distribution of any inventory but increased or decreased the volumes per acre by 20 percent for all age classes found in an initial inventory. The similarity of results between inventories and the symmetry of results for the increased and decreased adjustments to each inventory are evident.

For both adjustments, Inventory 4 shows the smallest percent differences for first and last decade harvests and total harvests and Inventory 6 shows the largest. First decade, last decade, and total harvest differences for the upward adjustment are overcuts of 13.3, 0.9, and 5.4 percent, respectively, for Inventory 4 and 17.1, 1.8, and 9.7 percent for Inventory 6. Undercut percent differences for the downward adjustment are, in the same order, -13.5, -1.0, and -5.5 percent for Inventory 4 and -17.5, -2.0, and -9.7 percent for Inventory 6. The negative sign indicates an undercut relative to the standard (or Base, in this case). Examination of the decade by decade differences shown in Figures A1 to A8 indicates that the harvest schedules for Inventory 6 consistenty show the largest percent differences for every decade. Inventory 4 consistently shows the smallest differences.

Harvest level differences due to simulated inventory errors seem to be independent of site class of the sample inventories. It is unclear how results may be related to initial stocking and age class distributions because harvest level differences are very similar for all the inventories and differences between inventory characteristics are not entirely distinct. It does appear that the extreme cases of Inventories 4 and 6 contradict conclusions reached by Fight and Schweitzer (1974) concerning effects of an inventory change on an allowable cut. Their conclusion was that harvest levels are relatively more affected by a change in initial inventory when the beginning inventory is small with an irregular age class distribution. Of all the sample inventories this best describes Inventory 4 and most poorly describes Inventory 6. Results are just reversed from the expected with Inventory 4 harvest schedules least affected relatively and those for Inventory 6 more affected than any others.

If the inventory error is half as large, ten percent, harvest level differences are half as large, too. This is shown by the results for Inventory 5 in Table 11B and Figure A5. While tentative because the comparison is made only for Inventory 5, the conclusion suggests a linear relationship between an inventory error and a harvest schedule change. Additional testing using other sample inventories, harvest scheduling methods, and sizes of inventory errors would be useful to substantiate this conclusion.

Yield models used in this study for extensive management included Bulletin 201 (McArdle et al. 1930), DFIT (Bruce et al. 1977, Reukema, Bruce 1977), DNR Empirical Yields (Chambers, Wilson 1972), Hoyer's Natural Stand Yields (Hoyer 1975), and Bulletin 201 less 15 percent. A description of yield development using these models was made in the previous chapter and the yields are shown in Tables 2A to 2C. These yields, in combination with approach to normality functions developed and shown previously (Table 5, Tables 6A to 6C, Figures 3A to 3C) and given management assumptions (Table 10), were used to develop harvest schedules. Results comparing Base to DFIT based harvest schedules, shown in Table 11C and Figures A9 to A16, show small first decade differences, ranging from 1.5 percent for Inventory 2 to -6.0 percent for Inventory 4. The negative sign indicates the harvest level generated using DFIT is smaller than the Base. Long-run sustained yield differences are generally larger and all are positive, ranging from a

TABLE 11C. PERCENT DIFFERENCES: BASE VS. DFIT

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	-2.8	14.4	7.7	A9
2	1.5	12.6	7.6	A10
3	1.0	18.2	11.4	A11
4	-6.0	5.1	0.2	A12
5	-4.0	12.5	5.4	A13
6	0.6	17.5	8.6	A14
7	-3.0	6.0	2.0	A15
8	-2.2	14.3	6.7	A16

low 5.1 percent for Inventory 4 to a high of 18.2 percent for Inventory 3. There seems to be a relationship between these differences and the site class of the sample inventory.

Generally, low site forests have first decade harvests using DFIT closest to those of the Base, with two of three having larger harvests. Medium site Inventories 4 and 7 have first decade differences which are most negative and those for high sites are generally between the other two. The same pattern is found for long-run and total percent differences with medium site harvest schedules using DFIT showing the least differences and low site ones the most. An exception to this pattern is the first decade difference for Inventory 2, a high site inventory, of 1.5 percent, which is the largest positive difference. This is probably due to a large old-growth component, few age class gaps, and the well-stocked nature of that inventory. These factors tend to dominate the short-term harvest levels and reduce the importance of future yield predictions.

The site index-percent difference relation just discussed can be explained by examining yield predictions shown in Tables 2A to 2C and approach to normality information discussed in the previous chapter (Table 5, Tables 6A to 6C, Figures 3A to 3C). Except for stands 45 years old to 135 years old stocked at less than 70 percent normal, DFIT predicts a faster approach to normal than Bulletin 201. DFIT generally predicts more normal yield per acre than Bulletin 201 with the exception of age classes beyond 55 on medium sites, thus explaining the pattern of medium site differences versus those of the other sites.

Given yield and approach to normality differences, why are some Bulletin 201 based harvest levels for early decades larger than those of DFIT based ones? A possible explanation is that holding the initial volume per acre fixed while enlarging the normal yield per acre by substituting larger DFIT yields for those of Bulletin 201 causes an inventory to appear more poorly stocked in percentage terms. The growth routine is based on these percentage stocking levels combined with an approach to normality function. It is possible to get less absolute growth in a period by starting with lower percent stocking levels that occur with higher DFIT yields.

An example will help clarify this point. Consider a 75 year old stand on high site, initially stocked at 80 percent on a Bulletin 201 volume basis. A comparison of ten year growth for this stand using a Bulletin 201 base and a DFIT base follows:

	Bulletin 201	DFIT
A. 75 year old normal volume (from Table 2A)	14,241	14,676

B. Initial volume/acre (.8 x 14,241)	11,393	11,393
C. Initial stocking - N_t % (B ÷ A)	.80	.7763
D. Stocking - $N_{t + 1}$ % (from Table 5)	.83	.81105
E. 85 year old normal volume (from Table 2A)	15,845	16,163
F. Actual volume - period t + 1 (D x E)	13,151	13,109
G. 10 year growth (F - B)	1,758	1,716

This result is more important when the intial inventory lacks a significant over-rotation-age component and is generally poorly stocked. This is also a result that loses significance over time as the initial stands are simulation harvested and replaced by new stands. In fact, an opposite effect happens because when a new 80 percent stocked stand is simulated it will have more volume when the larger normal DFIT yield is used than if a Bulletin 201 yield were used, thus the larger long-run harvests from simulations using DFIT yields.

This is evidence for a conclusion that early decade cut levels are much more dependent on intial inventory information than on future yield predictions. This is why first decade harvest level differences are so much closer to zero than are long-run differences, a result which appears in other comparisons as well.

General trends of results for DNR Empirical Yield based harvest schedules compared to the Base are similar to those just discussed. As seen in Table 11D and Figures A9 to A16, first decade percentage differences are again small, ranging from 3.3 percent for Inventory 3 to -7.3 percent for Inventory 4 with all but two having negative values, i.e., DNR based cuts are smaller. Last decade differences are larger and positive, ranging from a low of 4.6 percent for Inventory 8 to 17.6 percent for Inventory 2. The site class-percentage difference relationship is clear for long-run differences, with exception of that for Inventory 8, but a first decade pattern is not apparent. In terms of the long-run, high site inventory differences are about 17.5 percent, medium site ones are 8.6 percent, and low site relative differences are about 11.0 percent. Inventory 8, a low site inventory, has a long-run difference of only 4.6 percent. Compared to DFIT based long-run harvest levels, those based on DNR Empirical Yields are slightly higher for high and medium site inventories and lower for low site inventories.

Underlying reasons for the Base vs. DNR harvest level differences are found in the yield and approach to normality

TABLE 11D. PERCENT DIFFERENCES: BASE VS. DNR

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	-2.5	17.4	9.3	A9
2	2.2	17.6	10.5	A10
3	3.3	11.3	7.6	A11
4	-7.3	8.6	1.4	A12
5	-0.2	17.5	10.2	A13
6	-0.3	10.6	6.2	A14
7	-2.7	8.6	3.4	A15
8	-4.8	4.6	0.8	A16

information presented in the previous chapter. DNR predicts higher normal yields than Bulletin 201 for all age-site combinations except ages 25 to 55 years on medium site and ages 25 to 35 on low sites. The approach to normal comparison between Bulletin 201 and DNR Empirical shows a mixed pattern. Bulletin 201 generally predicts a faster approach to normal for the poorly stocked stands of less than about 50 percent stocking. DNR generally predicts a faster approach to normality for stands greater than 50 percent stocked and 35 years old or younger. The predictions are close to the same for other age-stocking combinations. In the long-run, the faster approach to normal predictions of Bulletin 201 for stands less than about 50 percent stocked lose importance as very few acres are simulation regenerated to such low stocking levels (Table 10, line 5).

As with the Base-DFIT comparison, the short-run differences in the DNR comparison are small or in fact negative because the initial inventory factor dominates any predicted future yield differences. In addition, less growth can occur when increasing the size of the normal yield without changing the initial inventory volume per acre results in poorer initial stocking percentages. Finally, some of the initial inventories have substantial amounts of poorly stocked acreage where Bulletin 201 is predicting a faster approach to normal and, therefore, more growth. In the long-run, those factors play less of a role as the inventory structure changes over time to a better stocked, generally younger condition. Higher normal yields per acre predicted by the DNR Empirical Yields and approximately equal approach to normality trends then result in higher long-run harvest levels as noted for the DNR simulations.

The results of the Base vs. Hoyer's Natural Stand Yield comparison presented in Table 11E and Figures A17 to A24 show the most pronounced relative differences of this study. As before, the first decade differences are smaller than the long-run, last decade differences with those for medium and low site inventories close to zero or negative. The probable explanation for this is the same as noted for the DFIT and DNR harvest level comparisons. Percent differences for the high site inventories are larger than in the other comparisons and positive with a high of 8.9 percent for Inventory 5. This is because the normal yields and approach to normal values predicted by Hoyer's Natural Stand Yields are enough larger than Bulletin 201 to outweigh the other factors discussed earlier.

As shown in Tables 2A to 2C, Hoyer's Natural Stand Yields are larger than those predicted by Bulletin 201 for all age-site combinations. They are also larger than either of the other two yield models with a couple of exceptions in

TABLE 11E. PERCENT DIFFERENCES: BASE VS. HOYER'S NATURAL

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	6.1	35.9	25.3	A17
2	4.6	34.2	21.6	A18
3	1.6	29.9	18.6	A19
4	-2.8	21.1	11.5	A20
5	8.9	35.8	25.6	A21
6	0.0	28.1	13.5	A22
7	-1.5	23.3	12.7	A23
8	-3.1	23.7	11.3	A24

younger age classes. Tables 6A to 6C and Figures 3A to 3C show that the approach to normal information developed in this study for the Hoyer yields are higher than those for Bulletin 201 for the younger ages and approximately equal for the medium age classes. The exact breakeven age is a function of the site class.

The higher normal yields and equal or faster approach to normality rates predicted by Hoyer's yields result in substantial last decade percent differences ranging from 21.1 percent for medium site Inventory 4 to 35.9 percent for a high site Inventory 1. The site class-percent difference pattern is reflected by the three high site inventories having the largest relative differences, the two medium site ones showing the smallest differences, and differences for the three low site inventories fall between them.

The effect on harvest schedules of an across-the-board 15 percent reduction in yield predictions is demonstrated by relative difference percentages of the Base vs. Bulletin 201 minus 15 percent comparisons. The similarity between results for different inventories is striking as shown in Table 11F. First decade differences are bunched between -3.3 percent and -4.8 percent with Inventory 6 varying slightly at -1.8 percent. The magnitude of these first decade differences substantiates the conclusion that short-term harvest levels are more influenced by initial

TABLE 11F. PERCENT DIFFERENCES: BASE VS. BULL. 201 - 15%

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	-4.2	-13.7	-10.4	A9
2	-4.2	-13.4	- 9.5	A10
3	-3.3	-13.9	- 9.5	A11
4	-4.8	-13.9	-10.6	A12
5	-3.8	-13.5	- 9.6	A13
6	-1.8	-13.4	- 7.5	A14
7	-3.5	-13.4	- 9.6	A15
8	-3.7	-14.0	- 9.5	A16

inventory data than by future yield predictions. Long-term harvest levels, on the other hand, are much more dependent on yield predictions and, as expected, the last decade differences are tightly bunched and approaching 15 percent. The pattern of differences over time for the various inventories, shown in Figures A9 to A16, are also very similar to each other regardless of site class or initial inventory structure.

Development of intensive management yields for Bulletin 201 and DFIT was described in the chapter on procedures. Those yields plus Bulletin 201 yields less 15 percent, shown in Tables 4A to 4C, can be compared to the corresponding extensive management yields of Tables 2A to 2C to see differences in normal per acre yields between low and high management intensity. That comparison for high site yields shows a substantial difference in Bulletin 201 predictions for younger ages. The difference gradually lessens as age increases. The difference in DFIT yields for different management intensities is small for younger ages and lessens with increasing age. The difference in yield changes has resulted in very similar predictions for high intensity management volumes by these two yield predictors with DFIT being only slightly higher.

A similar shifting pattern is seen for medium site class yields though DFIT yields shift upward slightly more than on high site. As before, Bulletin 201 yields shift upward significantly and are slightly higher than comparable DFIT yields. Both yield sets predict substantially more total cubic volume production under an intensive management regime than an extensive one for low site class. Bulletin 201 predicts higher yields for age 25 and 35 while DFIT predicts higher yields for age 45 and older with the difference increasing with increasing age.

Increased total cubic volume yield per acre from normal stands is a benefit of intensive forest management that results from higher growth rates. Other benefits include shorter regeneration lags, higher regeneration stocking levels, less unsalvaged mortality, and a faster conversion rate of non-producing brushland into timber production (Johnson et al. 1975). These benefits are reflected in this study by the assumptions shown in Table 10. The magnitude of benefit from these items is dependent upon the specific before and after assumptions selected to represent them.

Important economic benefits from intensive management practices are not reflected in results of this study. Precommercial and commercial thinning both result in increased diameter growth rates of remaining crop trees. These larger, high quality trees bring higher unit stumpage values to a landowner because of lower logging costs and a quality premium in mill delivered prices. As previously noted, these larger diameter trees can result in increased yields in terms of Scribner board feet, the volume unit most commonly used in the Pacific Northwest today, a result ignored in this study because of the use of total cubic feet. In addition, an earlier return on investments from intermediate commercial harvests is a benefit not evaluated in this study.

A comparison between the Base, or Bulletin 201 for extensive management, and harvest schedules based on Bulletin 201 for intensive management is shown in Table 11G. First decade differences are all positive ranging from 2.7 percent for Inventory 5 to 7.0 percent for Inventory 3. These short-term gains reflect the immediate availability of commercial thinning volumes for harvest; essentially an increase in initial inventory (Fight, Schweitzer 1974). This additional volume can be used to maintain harvest levels when shortages due to age class gaps would otherwise force decreases. Transitions from first decade differences to last decade differences shown in Figures A9 to A16 are variable and irregular though all show at least the second and third decade differences to be larger than that for the first decade.

Last decade differences show a relationship to the site class of the inventory. High site inventories show small gains of approximately one percent. Medium site inventories

TABLE 11G. PERCENT DIFFERENCES: BASE VS. BULL. 201 INTENSIVE MANAGEMENT

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	5.2	1.1	2.4	A9
2	3.8	1.3	2.5	A10
3	7.0	9.9	9.4	A11
4	6.3	2.7	5.0	A12
5	2.7	0.4	0.3	A13
6	5.2	9.6	8.2	A14
7	5.4	3.2	4.3	A15
8	6.2	8.5	8.7	A16

show slightly larger gains of about three percent and low site inventories show approximately nine percent gains in long-term harvest levels. These results reflect the combined effects of different yields and different management assumptions and it is difficult to separate them. In addition, complicated shifts in growing stock levels due to commercial thinning activities and approach to normality changes are reflected in these final results.

This last factor is a moderating influence on the effects of increased per acre yields and increased expectations of management activities. Relative harvest level differences would be larger if only these two factors were involved but thinnings reduce the percent stocking levels and, therefore, total cubic volume growth. An example will help clarify this point. Consider a 45 year old stand on medium site initially stocked at 95 percent of Bulletin 201 predicted volume. A comparison of ten year growth for this stand unthinned and thinned follows:

	Unthinned	Thinned
A. 45 year old normal volume (from Table 2A)	7,036	7,036
B. Initial volume/acre (.95 x 7,036)	6,684	6,684
C. Thinning volume/acre	--	1,727
D. Volume after thinning (B - C)	6,684	4,957

E. Stocking after thinning - N_t (D ÷ A)	95%	70.5%
F. 10 year stocking - N_{t+1} (from Table 5)	96.5%	74.45%
G. 55 year old normal volume (from Table 2A)	8,581	8,581
H. Actual volume - period t + 1 (F x G)	8,281	6,389
I. 10 year growth (H - D)	1,597	1,432

Less total cubic volume growth from thinned stands than unthinned ones is a factor causing last decade differences to be negative for high and medium site inventories in the DFIT extensive versus intensive management comparisons shown in Table 11H and Figures A39 to A46. This factor outweighs the increased yields, which were small for high and medium site, and the change in management assumptions. For low sites the higher last decade harvest levels for intensive management of about 8.5 percent reflect the sizeable increase in yield from intensive management. The short-term first decade increases in harvests shown by all inventories again reflects additional volume available from commercial thinning helping to fill in shortages caused by age class deficiencies. The first decade differences are considerably

TABLE 11H. PERCENT DIFFERENCES: DFIT VS. DFIT INTENSIVE MANAGEMENT

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	13.5	-8.7	-0.1	A39
2	9.6	-8.1	0.2	A40
3	10.4	8.9	10.8	A41
4	11.3	-1.7	6.8	A42
5	10.1	-9.4	-1.2	A43
6	7.0	8.8	9.9	A44
7	9.3	-1.1	4.9	A45
8	8.1	8.2	10.8	A46

larger than those of the Bulletin 201 comparisons.

Comparisons of harvest schedules using Bulletin 201 intensive management yields and DFIT intensive management yields are shown in Table 11I and Figures A31 to A38. With two minor exceptions, all first decade differences show DFIT based harvest levels to be slightly higher with a maximum difference of 7.2 percent for Inventory 2. The two exceptions show higher DFIT based harvests in decade two and beyond. With high and medium site inventories the harvest level differences are relatively stable over time with Bulletin 201 based harvests being only slightly lower. Low site differences increase gradually over time until reaching the last decade where DFIT based harvests are 13.9 percent to 17.1 percent higher. These results are not surprising because the harvests are dependent on yield information of Tables 4A to 4C and approach to normality information of Tables 6A to 6C. Generally, Bulletin 201 yields are slightly conservative relative to DFIT's for high and medium sites and significantly more conservative for low sites. Management assumptions are the same and play no role in the differences. Both involve growth after thinning so that is no longer a dominant factor though growth is not necessarily equal because of differences in approach to normality predictions.

A worst-possible-case situation is examined to

TABLE 11I. PERCENT DIFFERENCES:BULL. 201 INTENSIVE MANAGEMENT VS. DFIT INTENSIVE MANAGEMENT

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	4.8	3.3	5.1	A31
2	7.2	2.2	5.2	A32
3	4.1	17.1	12.9	A33
4	-1.6	0.6	2.0	A34
5	3.0	1.5	3.8	A35
6	2.3	16.6	10.3	A36
7	0.6	1.6	2.5	A37
8	-0.4	13.9	8.7	A38

determine the combined effects of errors in initial inventory data and in future yield predictions. Bulletin 201 yields for intensive management are reduced by 15 percent and used with initial inventories that were reduced by 20 percent. Results, shown in Table 11J and Figures A31 to A38, are remarkably similar to each other with no apparent effects of site or initial inventory characteristics. The assumed data errors are large; especially considering they were all made in the same direction ignoring the more likely case of compensating errors. Based on earlier results, a probable conclusion is that the 18 plus percent first decade differences are primarily due to the initial inventory errors while the last decade differences of slightly over 15 percent are the result of the reduced yield predictions. During the transition time the effect of one factor is gradually replaced by the other.

Effects of slightly fluctuating site indexes as noted earlier was tested by using yields from a fixed site index in the yield table input format of the TREES model. Results shown in Table 11K indicate a trivial effect. Apparently the concern expressed earlier about the need to maintain equivalent site indexes in order to make the harvest level comparisons valid was overstated.

On the other hand, a concern about the significance of

TABLE 11J. PERCENT DIFFERENCES: BULL. 201 INTENSIVE MANAGEMENT VS. BULL. 201 INTENSIVE MANAGEMENT - 15% AND INVENTORY X - 20%

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
1	-18.5	-15.2	-16.3	A31
2	-18.3	-15.4	-16.6	A32
3	-18.6	-15.2	-16.5	A33
4	-17.8	-15.1	-16.2	A34
5	-18.5	-15.5	-16.5	A35
6	-18.8	-15.2	-17.0	A36
7	-18.3	-15.4	-16.5	A37
8	-18.3	-15.2	-16.5	A38

approach to normal information seems valid. Because of the uncertainty of approach to normal rates developed for this study, tests were conducted to determine effects of those rates on the harvest level differences being reported. Tests involved combining approach to normal rates developed for one yield set with yields predicted by a different model. Results shown in Tables 11L, 11M, and 11N suggest the effects of approach to normality information on computed harvest levels are important.

Bulletin 201 yields were combined with the approach to normal predictions from DFIT and the simulated harvest levels were compared to those using Bulletin 201 yields with Bulletin 201 approach to normal predictions. Little difference was observed in first decade harvests. Table 11L and Figures A25 to A27 show that these small differences increased steadily over time until the last decade when percent differences approximated ten percent. These last decade differences were the result of changed approach to normality functions interacting with the yield predictions and the management assumptions that were unchanged.

Similar results for Inventory 5 are shown in Table 11M and Figures A25 and A28. Bulletin 201 approach to normal predictions were combined in simulations with DFIT yield information. When DFIT based schedules were compared to the Base a first decade difference of -4.0 percent increased

TABLE 11K. PERCENT DIFFERENCES: BASE VS. BULL. 201 WITH FIXED SITE INDEX

Inventory (S.I.)	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
5(185)	1.1	1.7	1.5	A25
6(100)	-0.9	-0.1	-0.4	A26
7(140)	-0.9	1.0	-0.0	A27

TABLE 11L. PERCENT DIFFERENCES: BULL. 201 WITH DFIT APPROACH TO NORMALITY

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
5	-0.6	9.8	5.6	A25
6	0.3	11.4	5.6	A26
7	-2.1	9.4	4.5	A27

TABLE 11M. PERCENT DIFFERENCES: BASE VS. DFIT WITH BULL. 201 APPROACH TO NORMALITY (BASE VS. DFIT) ((DFIT VS. DFIT WITH BULL. 201 APPROACH TO NORMALITY))

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
5	-2.9	2.3	-0.1	A25
(5	-4.0	12.5	5.4	A25)
((5	1.2	-9.1	-5.2	A28))

TABLE 11N. PERCENT DIFFERENCES:
BASE VS. HOYER WITH BULL. 201
APPROACH TO NORMALITY
(BASE VS. HOYER)
((HOYER VS. HOYER WITH BULL. 201
APPROACH TO NORMALITY))

Inventory	%1st Decade Difference	%Last Decade Difference	%Total Difference	Figure
5	3.5	12.9	9.3	A21
(5	8.9	35.8	25.6	A21)
((5	-5.0	-16.8	-13.0	A28))
6	1.2	21.4	11.3	A22
(6	0.0	28.1	13.5	A22)
((6	1.2	- 5.3	- 1.9	A29))
7	0.9	9.7	6.1	A23
(7	-1.5	23.3	12.7	A23)
((7	2.4	-11.1	- 5.9	A30))

gradually but steadily to a 12.5 percent difference in the last decade. With DFIT yields combined with the Base approach to normality those differences lessened to -2.9 percent for the first decade and 2.3 percent for the last, a substantial difference. Substituting Bulletin 201 approach to normality predictions increased DFIT based first decade harvests by 1.2 percent but substantially reduced long-term harvests by over nine percent. Mixing Hoyer yields with Bulletin 201 approach to normal information is demonstrated for Inventories 5, 6, and 7 in Table 11N and Figures A21 to A23 and A28 to A30. Percent differences between long-run Base harvest schedules and those using Hoyer's Natural Stand Yields were easily the largest of any observed in this study. The approach to normality information developed for the Hoyer yields also was the most troublesome. Comparisons were made to determine the impact of approach to normal predictions on harvest level differences.

Changing the approach to normality information substantially reduced the size of the long-run differences, especially on high and medium site inventories where differences were reduced by two-thirds and one-half, respectively. Only on high site Inventory 5 was the change in the first decade difference important, reduced from 8.9 percent to 3.5 percent. The long-term difference between low site Inventory 6 harvest schedules remains relatively large after the approach to normal change at 21.4 percent or slightly less than a 25 percent reduction from what it was.

These changes are not simply an additive influence of the approach to normal information but reflect an interaction of that information with yield data and management assumptions.

When growth is calculated as the difference between yields at two time periods and those yields are computed as a percentage of a standard normal volume, the approach to normal information used to establish those percentages is as important as the yield predictions themselves. Approach to normality predictions are an integral part of yield models when variable density stocking is considered.

V. SUMMARY and CONCLUSIONS

The objective of this study was to determine the sensitivity of planned harvest levels to two key input items of the planning process; future yield predictions and initial forest inventory data. Both items are uncertain by nature so it is important for forest planners to be aware of the impacts of errors in them on planned harvest levels. Established yield models for Douglas-fir were used as yield predictors so the objective can be restated as to determine the differences between the established yield models when used in a harvest scheduling context.

The study was conducted by using the sequential even-flow option of the TREES simulation model (Tedder et al. 1980) to develop harvest plans for eight different sample inventories. Each inventory represented a hypothetical Pacific Northwest forest composed of land of a single site class. A ceteris paribus format was used where either the inventory was adjusted or the yield model was changed while holding all else constant. Each simulated harvest plan was, therefore, unique to a given set of inputs. A sensitivity analysis was done by comparing periodic and total planning horizon harvest levels in terms of relative differences in percent. Emphasis was placed on first decade harvests because of the immediacy of their implementation and last decade harvests because they approximate potential long-term sustained yield.

An error in the initial inventory data was represented by a 20 percent change in initial volumes per acre applied to all age classes. This changed first period harvests by between 13 percent and 17 percent. As expected, long-run differences were small and in the very long run would be negligible. These results should be reassuring to inventory specialists and forest planners who know that compensating errors among volume estimates for various age classes would probably bring the total forest estimate closer to the actual volume than 20 percent. In a case examined using Inventory 5, both short-run and long-run percent differences were halved when the initial error was halved. This suggests a linear relationship between initial inventory error and change in harvest level; a conclusion which requires more testing with other inventory structures, harvest scheduling techniques, and inventory adjustments in order to substantiate it.

Extensive management yields from Bulletin 201 (McArdle et al. 1930) were used as the base yields because of their historical, widespread use. Extensive management involves a final clearcut harvest and regeneration only. These yields plus those of the other models used in this study represent predictions of harvestable volume from the normal or natural stand. Normal stands have many more trees per acre than artificially established plantations which are closer to precommercially thinned stands in terms of the size and character of the yields (Reukema 1979). A useful extension of this study would be to develop extensive management yields from artificially established plantations and compare harvest schedules using them to those using normal extensive management yields from this study. This would be especially useful if merchantable volume or an economic criterion was being used for the comparison instead of total cubic volume as used here.

Comparisons of harvest schedules developed using different established yield models show small, mixed first decade differences. First decade harvest levels are dominated by initial inventory stocking levels and age class distributions rather than by future yield predictions. Long-run differences are dependent on the interaction of yield and approach to normality predictions with management assumptions.

Specific long-run differences are dependent on the yield model and the site class of the test inventory. Long-run harvest levels based on Bulletin 201 yields are conservative relative to the other yield models tested; by as much as 18.2 percent with DFIT (Bruce et al. 1977, Reukema, Bruce 1977) and a low site class inventory, up to

17.6 percent with DNR Empirical yields (Chambers, Wilson 1972) and a high site class inventory, and up to a large 35.9 percent on a high site class inventory with Hoyer's Natural Stand yields (Hoyer 1975). Across the board 15 percent reductions in future yield predictions reduced first decade harvests by only three percent to four percent which should be reassuring to forest management planners. As expected, long-run differences are approaching 15 percent.

Approach to normal information is used for estimating growth of non-normal, irregular stands. Though of an uncertain nature, these predictions appear to be an important part of a yield model when dealing with variable stocked stands. A large portion of the differences between last decade harvest levels based on different yield models seems to be attributable to the approach to normality function. Short-run differences change very little but long-run differences change substantially when normality predictions are changed. The differences between Bulletin 201 based harvest schedules and those based on other yield models lessen substantially when Bulletin 201 approach to normal information is combined with those other yields.

Both Bulletin 201 and DFIT show positive first decade gains from intensive management due to additional volume immediately available from commercial thinning. DFIT gains averaged about ten percent and Bulletin 201 gains averaged about five percent over their respective extensive management yields. Both Bulletin 201 and DFIT predict long-run gains of about nine percent from intensive management on low sites. Bulletin 201 predicts positive long-run gains on medium and high sites but they are small because commercial thinning reduces total cubic volume growth due to a reduction in growing stock. With DFIT, this factor outweighs anticipated gains in normal yields and management successes resulting in lower long-run harvest levels from intensive management of about 8.5 percent on high site class land and 1.5 percent on medium site areas. Bulletin 201 based harvest levels are conservative when compared to DFIT based ones, especially for long-run harvests on low site forests.

This study was not an analysis of the benefits of intensive forest management. It should not be interpreted as such because the only comparison criterion used was total cubic volume production, not usable yield. The key to evaluating intensive management investments is to examine economic benefits, not biological gain. This is a well established guide for individual stand analysis which should be incorporated in forest level analysis as well. A useful extension of this study would be to better incorporate intensive management yields from various sources into a similar ceteris paribus format. Such sources include the

Level-of-Growing-Stock Cooperative Study (Williamson et al. 1971), DNR Managed Stand Yields (Hoyer 1975), and DFSIM (Curtis 1980). Useful criteria to make comparisons of forest level plans on an economic basis might include cash flow, employment, missed opportunities, potential shortages, and total forest present net value.

Various responses to the results of this study are possible from forest managers depending upon their opinion about the significance of the reported differences and their attitude toward risk. They could choose the yield and approach to normal information that is the most conservative or, conversely, the most optimistic. They could feel compelled to intensify their forest inventory program knowing that short-run harvest levels are more sensitive to current inventory information than long-run growth predictions. They might arbitrarily adjust harvest recommendations downward to provide a buffer against uncertainty or they may feel reassured by the reported differences. If so they would support the argument that the reported differences are small and insignificant.

What constitutes a significant difference? Nothing has been or can be said about the statistical accuracy of the predictions or the differences between them. Work is needed on ways to identify and incorporate variability into the point estimates of recommended harvest levels. Without such variability estimates it is impossible to say whether or not differences are statistically significant. What is a significant difference in a non-statistical sense; especially considering the frequent updating of harvest plans that is done? Though certainty and completeness of information is often assumed, it is precisely because of the lack of those two items that frequent revisions are conducted. In addition, are the reported differences of this study significant when operational harvests can vary more than those differences from the target levels due to market fluctuations, owner needs, and logistical constraints?

Finally, biological and economic uncertainty abound in forestry because of a long-term production process. Are the differences that result from a change in the yield model or an initial inventory error significant when there is uncertainty about several other important factors that affect harvest schedules? These include shifting owner objectives, shifts in merchantability standards and utilization levels, site class determination, irregular mortality, land base changes, changes in the economic value of the resource, and shifting environmental constraints. This study has established ranges of differences resulting from yield or inventory changes. It has not answered the questions about the significance of those differences.

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APPENDIX

HARVEST LEVEL DIFFERENCE FIGURE DESCRIPTION

As indicated in the results chapter, relative differences between two comparable harvest schedules rather than absolute differences are the most important results. Differences for all comparison pairs identified in the methods chapter and shown in Table 9 are demonstrated in Figures A1 to A46.

The graphs show relative percent difference by decade between two harvest schedules computed as follows:

$$\% \text{ Rel. Diff.} = \frac{X_{2i} - X_{1i}}{X_{1i}} (100)$$

Where: X_{1i} = Harvest volume for the $i^{\underline{th}}$ decade of the simulation listed first in the graph heading (to the left of Vs.)

X_{2i} = Harvest volume for the $i^{\underline{th}}$ decade of the simulation listed second in the graph heading (to the right of Vs.)

i = Decade in the planning horizon; i.e., 1 to 13

For example, Figure A1, which pertains to results for Inventory 1, shows percent harvest level differences between the Base for Inventory 1 and the simulation where initial inventory volumes per acre for all age classes were increased by 20 percent, shown by the solid line. Because Base is listed first in the figure heading, the harvest volume from that schedule for the i^{th} decade is X_{1i} in the percent difference formula. The i^{th} decade harvest volume for the adjusted inventory simulation is X_{2i}.

Harvest level percent differences for more than one combination are shown on most figures. For example, the percent differences between the Base and an adjusted initial Inventory 1 where the volumes per acre are decreased by 20 percent are also shown in Figure A1. These are shown by the line dashed in the horizontal sections. A particular figure, however, is restricted to showing results pertaining to only one inventory.

As indicated in the methods chapter, Base refers to the simulation which used Bulletin 201 yields for extensive management and an unadjusted initial inventory. There are eight Base simulations, one for each inventory.

Int. Mgt. means the intensive management yields for the indicated yield predictor were used in the simulation being compared. If Int. Mgt. is not present assume extensive management yields.

Note that the vertical percent difference scale is different for Figures A17 to A24 than for all the rest.

FIGURE A1. HARVEST LEVEL DIFFERENCE
INVENTORY 1

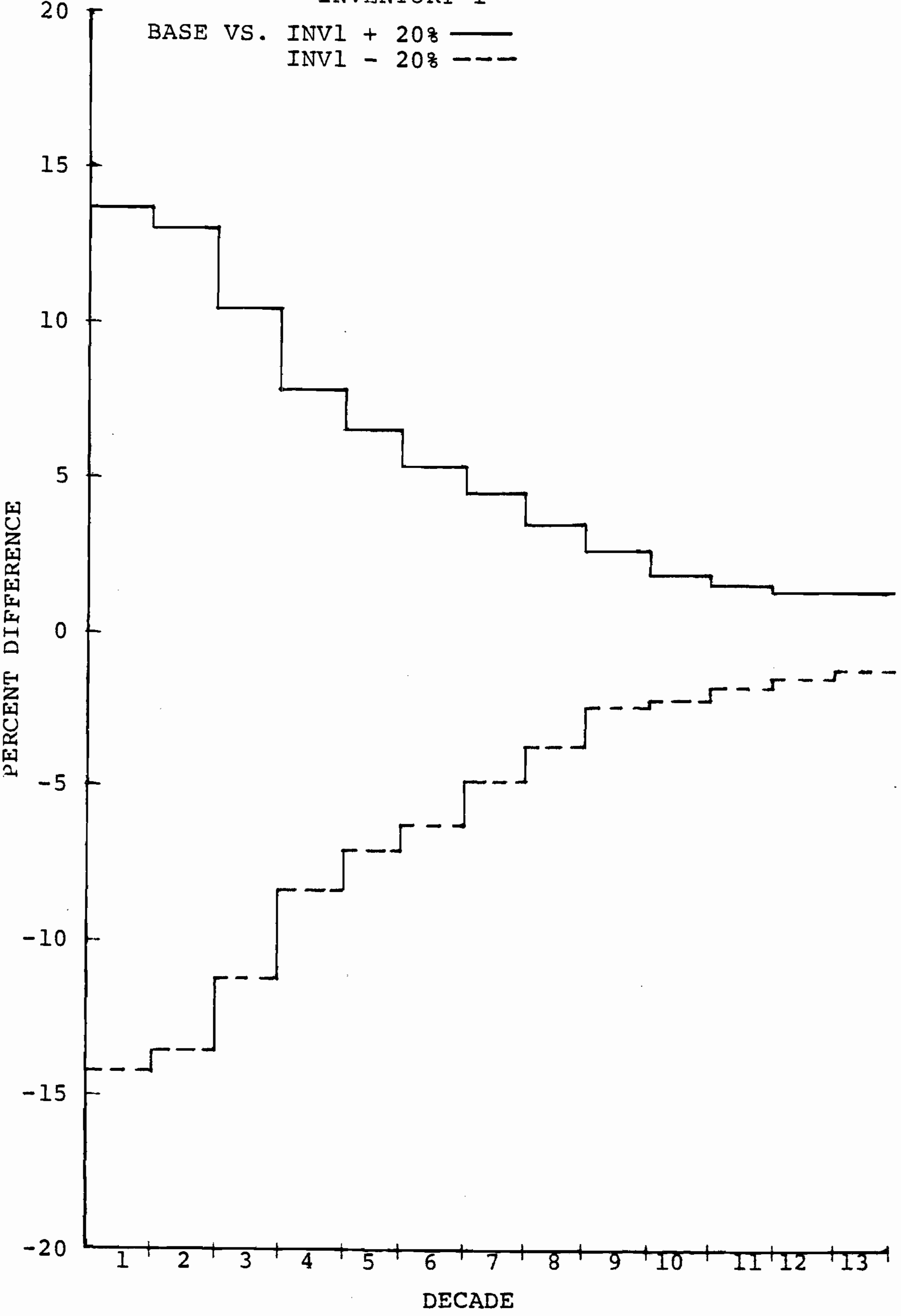

FIGURE A2. HARVEST LEVEL DIFFERENCE
INVENTORY 2

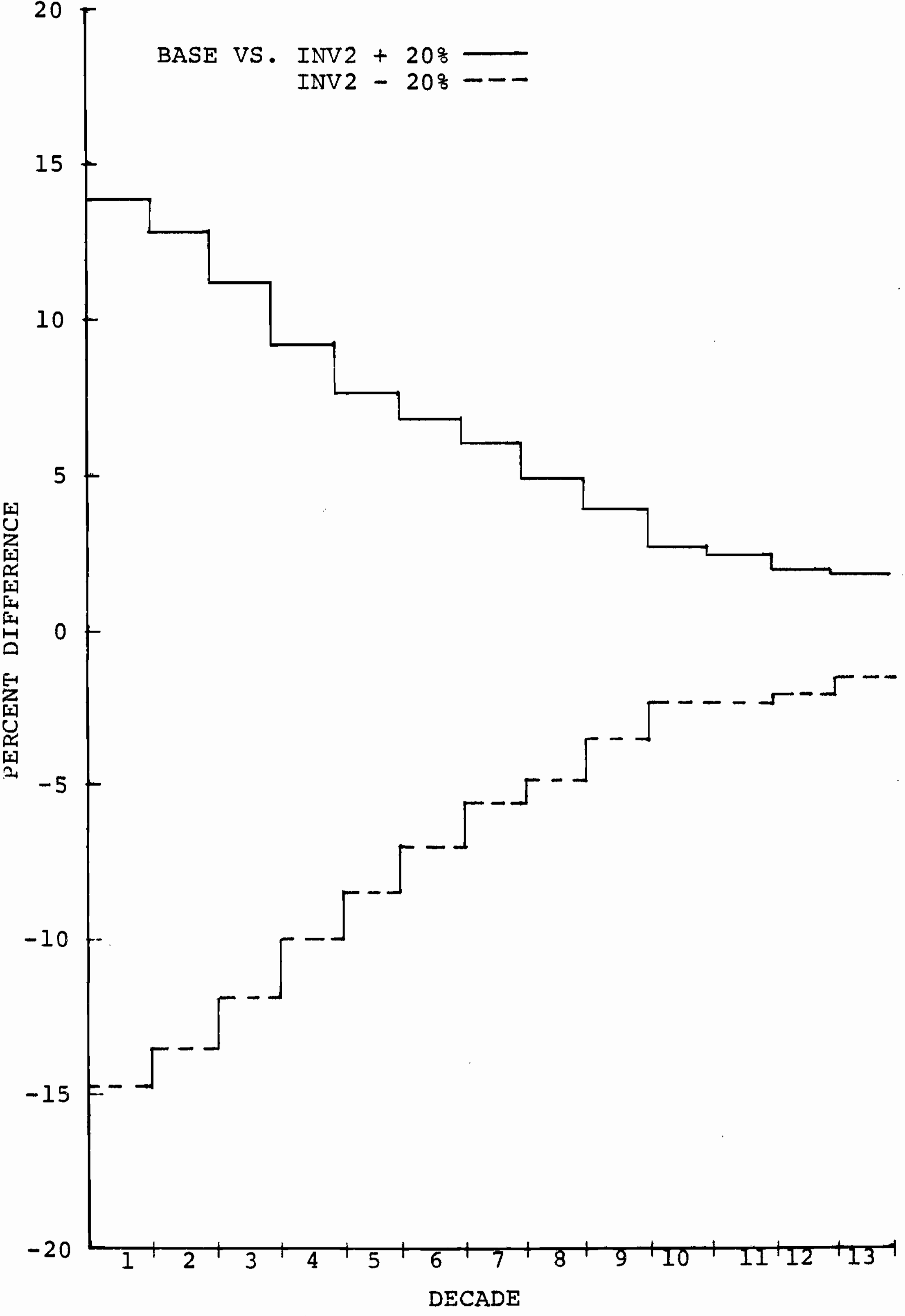

FIGURE A3. HARVEST LEVEL DIFFERENCE

INVENTORY 3

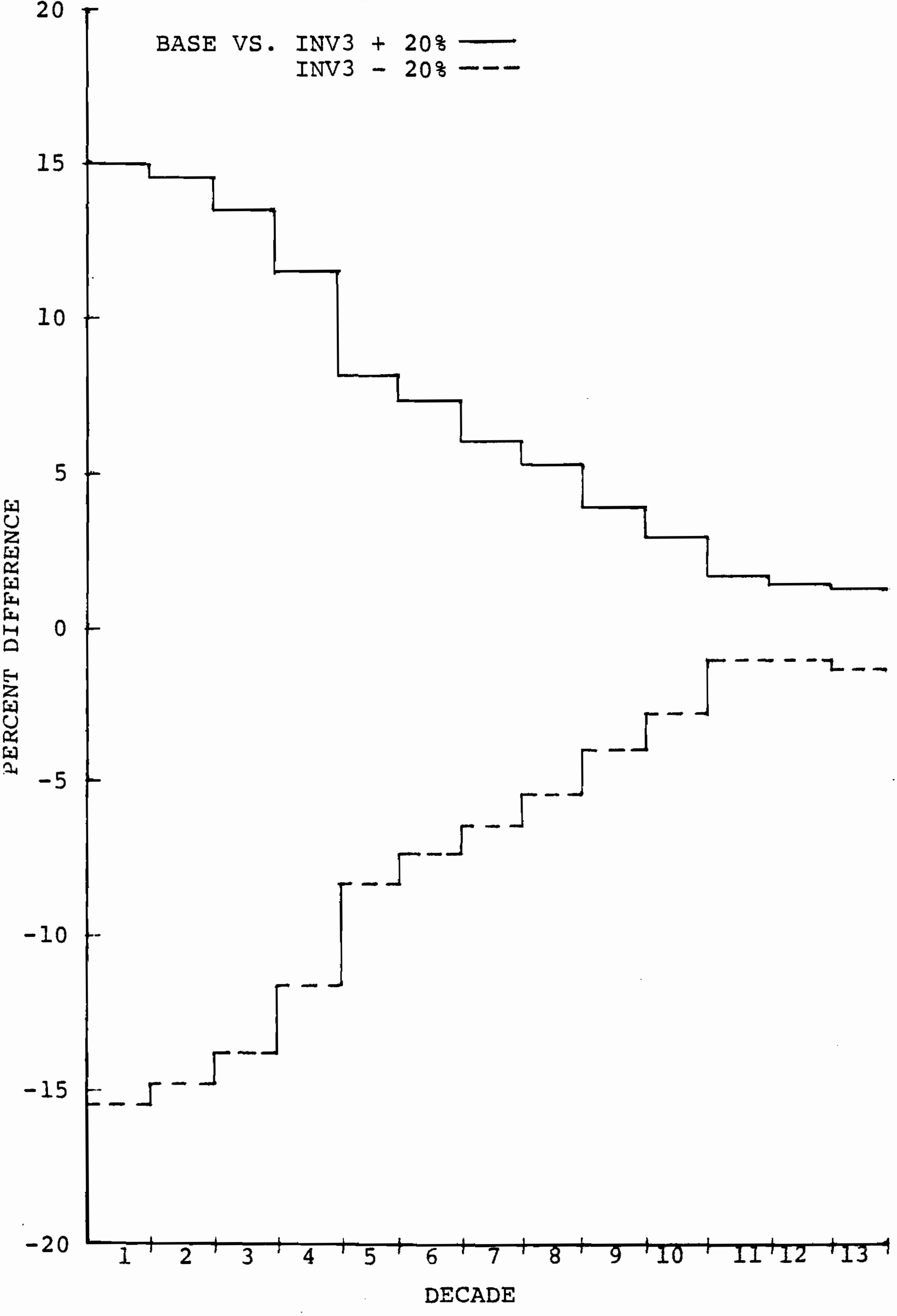

FIGURE A4. HARVEST LEVEL DIFFERENCE
INVENTORY 4

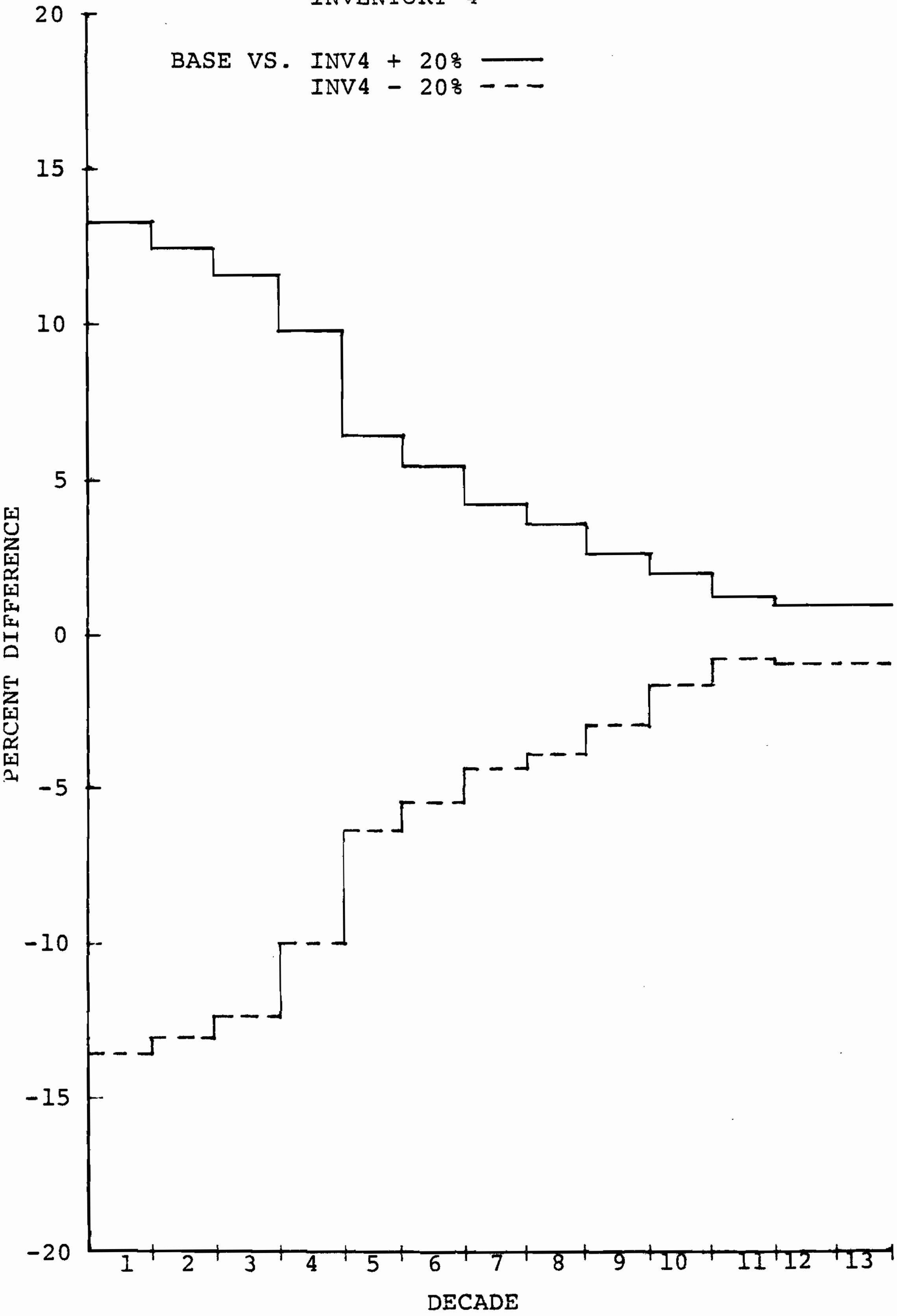

FIGURE A5. HARVEST LEVEL DIFFERENCE
INVENTORY 5

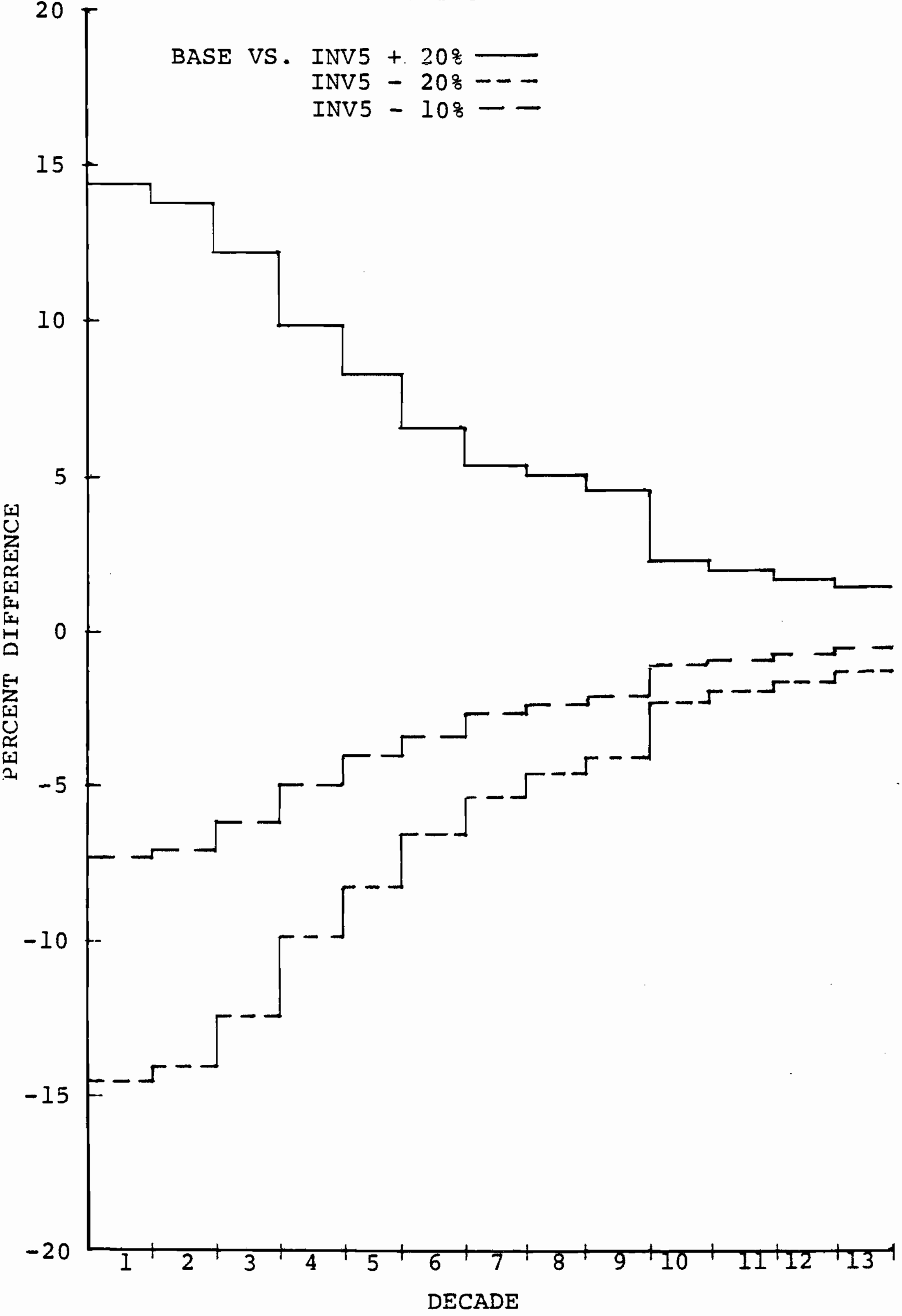

FIGURE A6. HARVEST LEVEL DIFFERENCE
INVENTORY 6

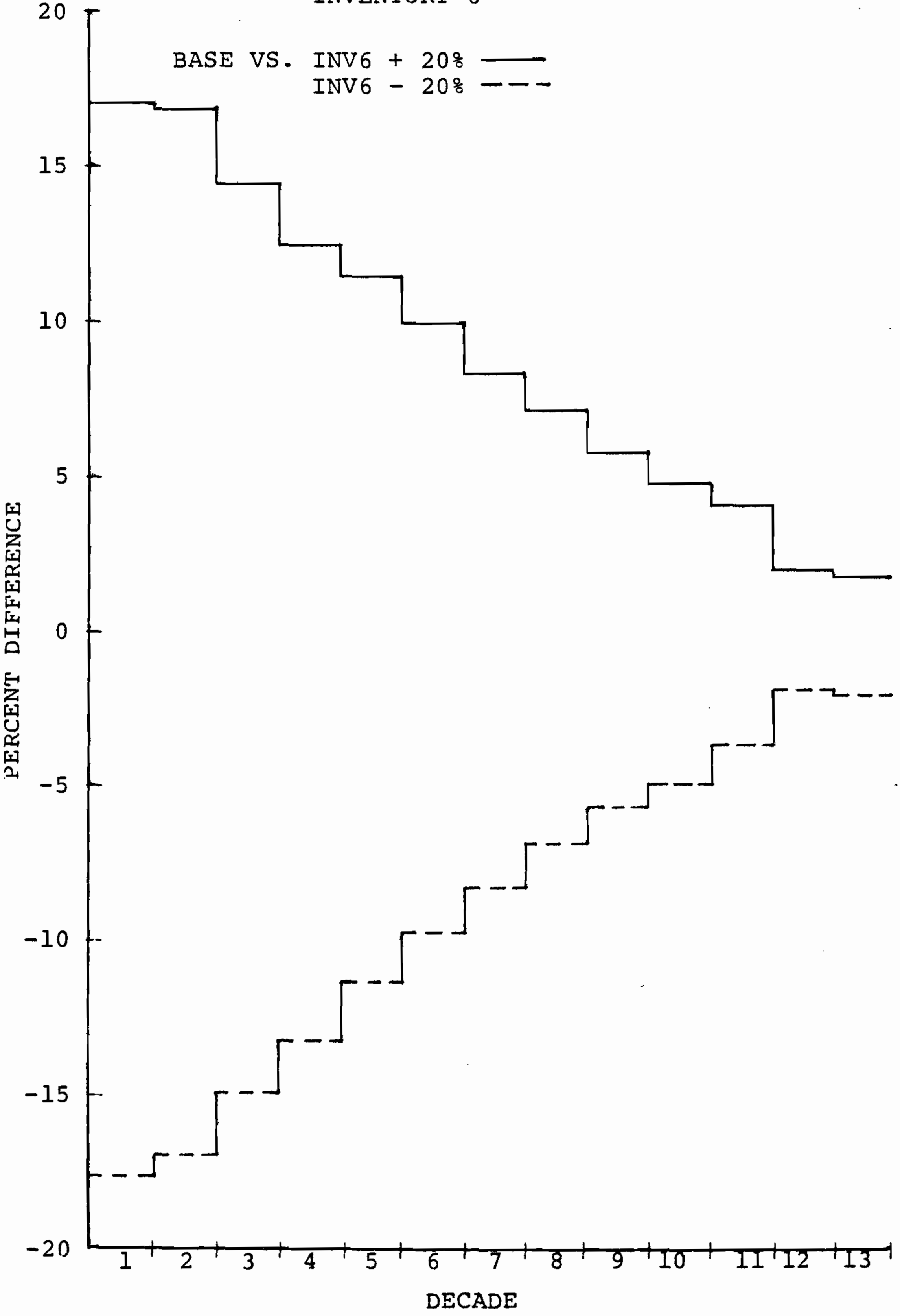

FIGURE A7. HARVEST LEVEL DIFFERENCE

INVENTORY 7

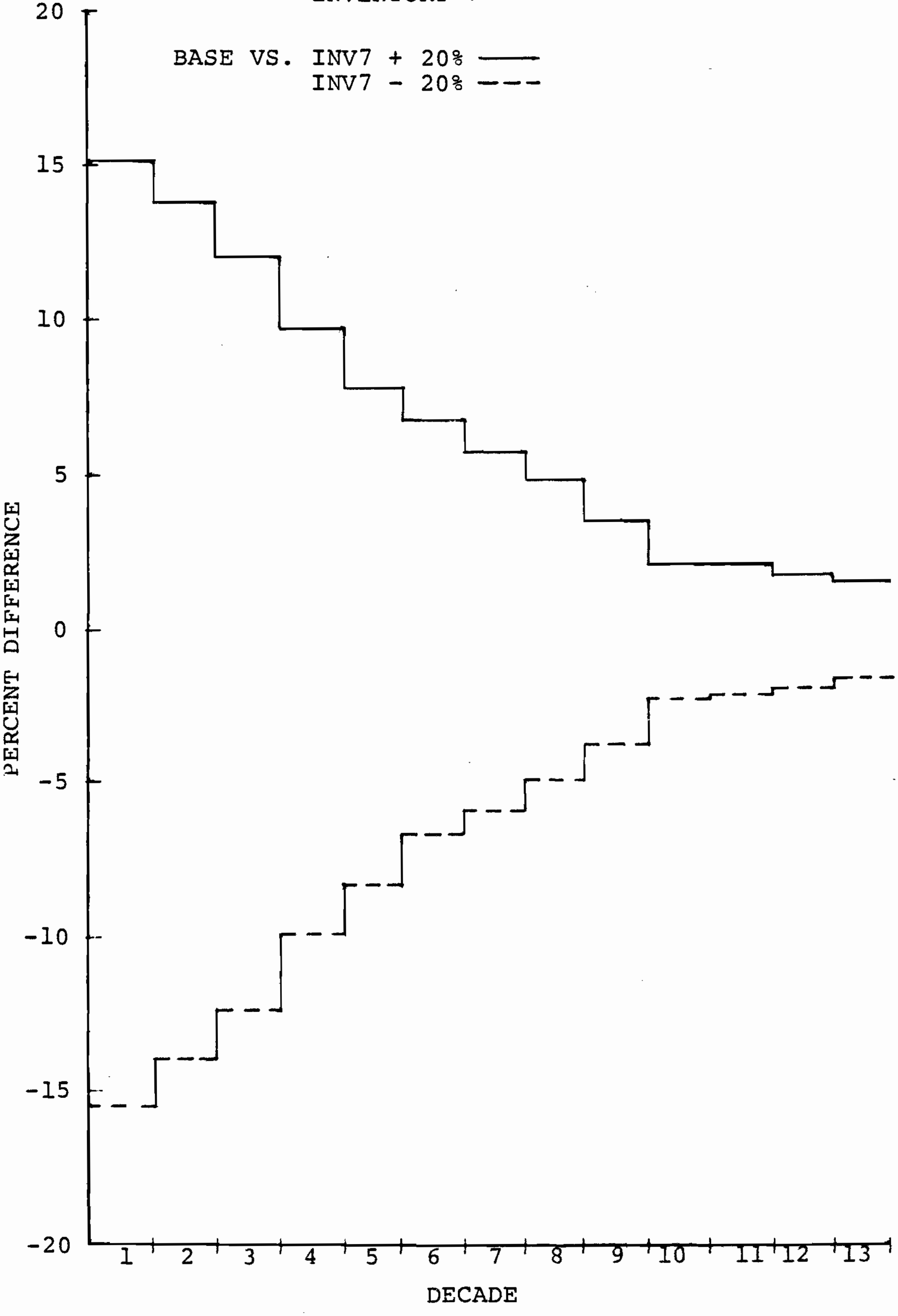

FIGURE A8. HARVEST LEVEL DIFFERENCE
INVENTORY 8

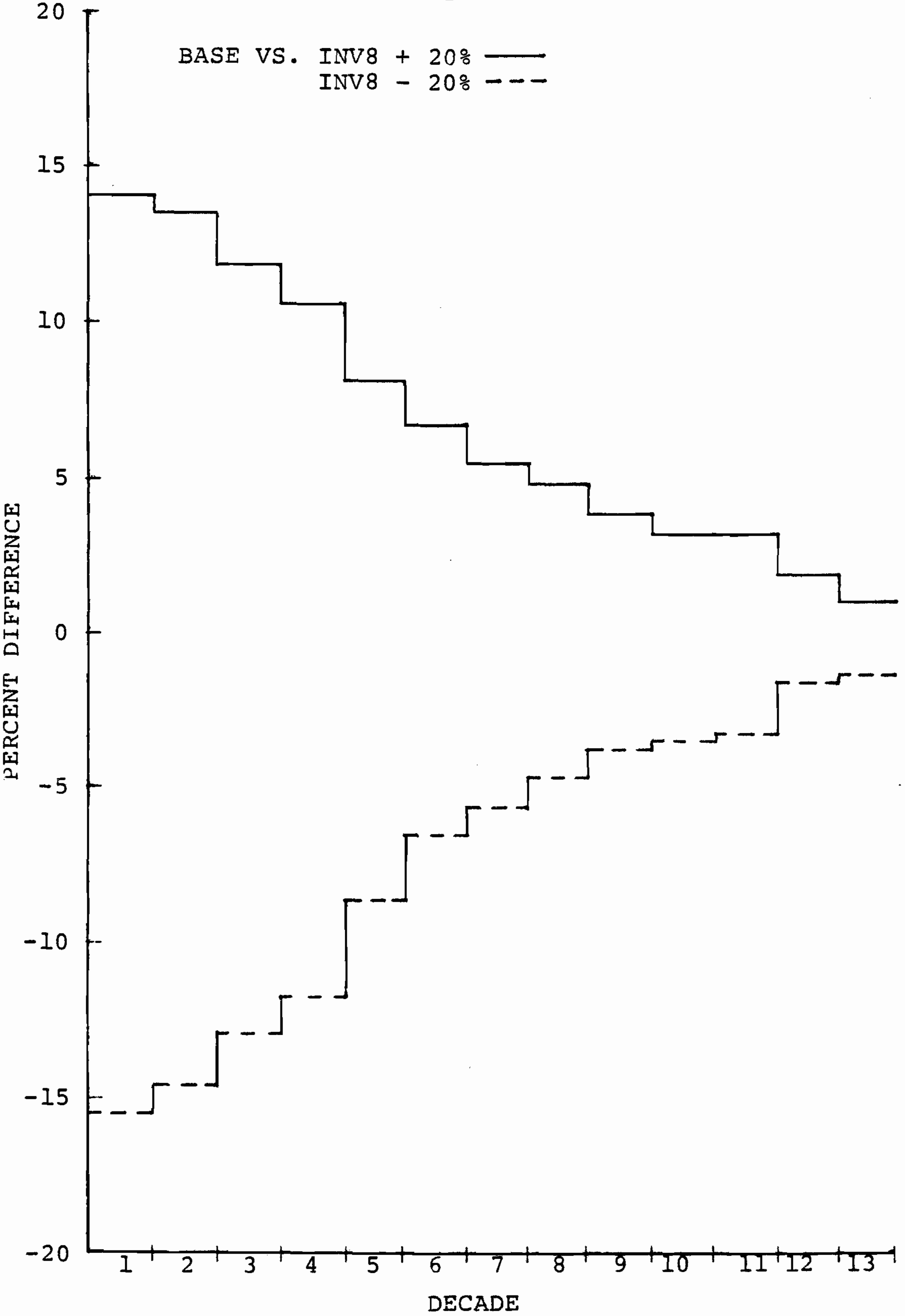

FIGURE A9. HARVEST LEVEL DIFFERENCE
INVENTORY 1

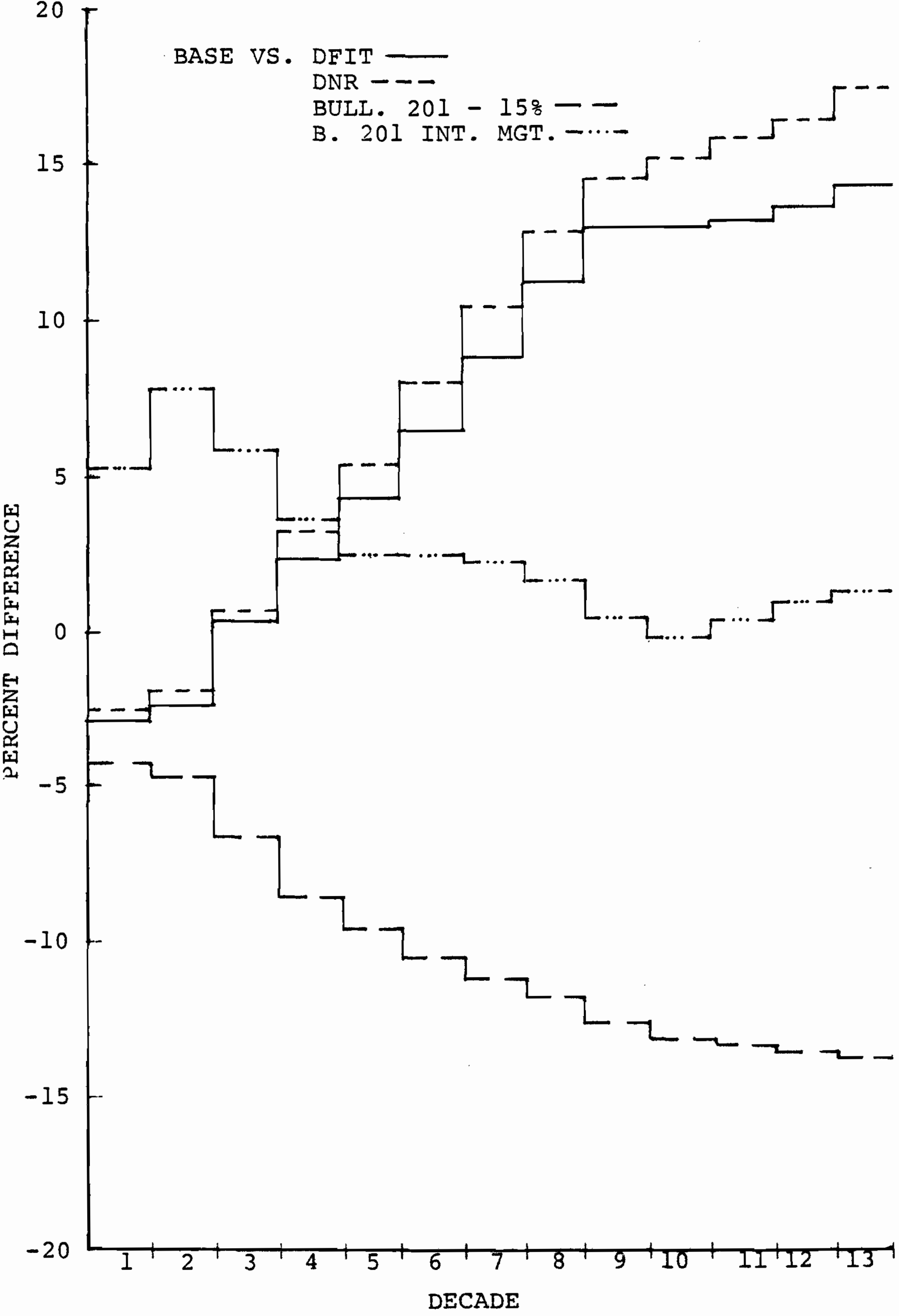

FIGURE A10. HARVEST LEVEL DIFFERENCE
INVENTORY 2

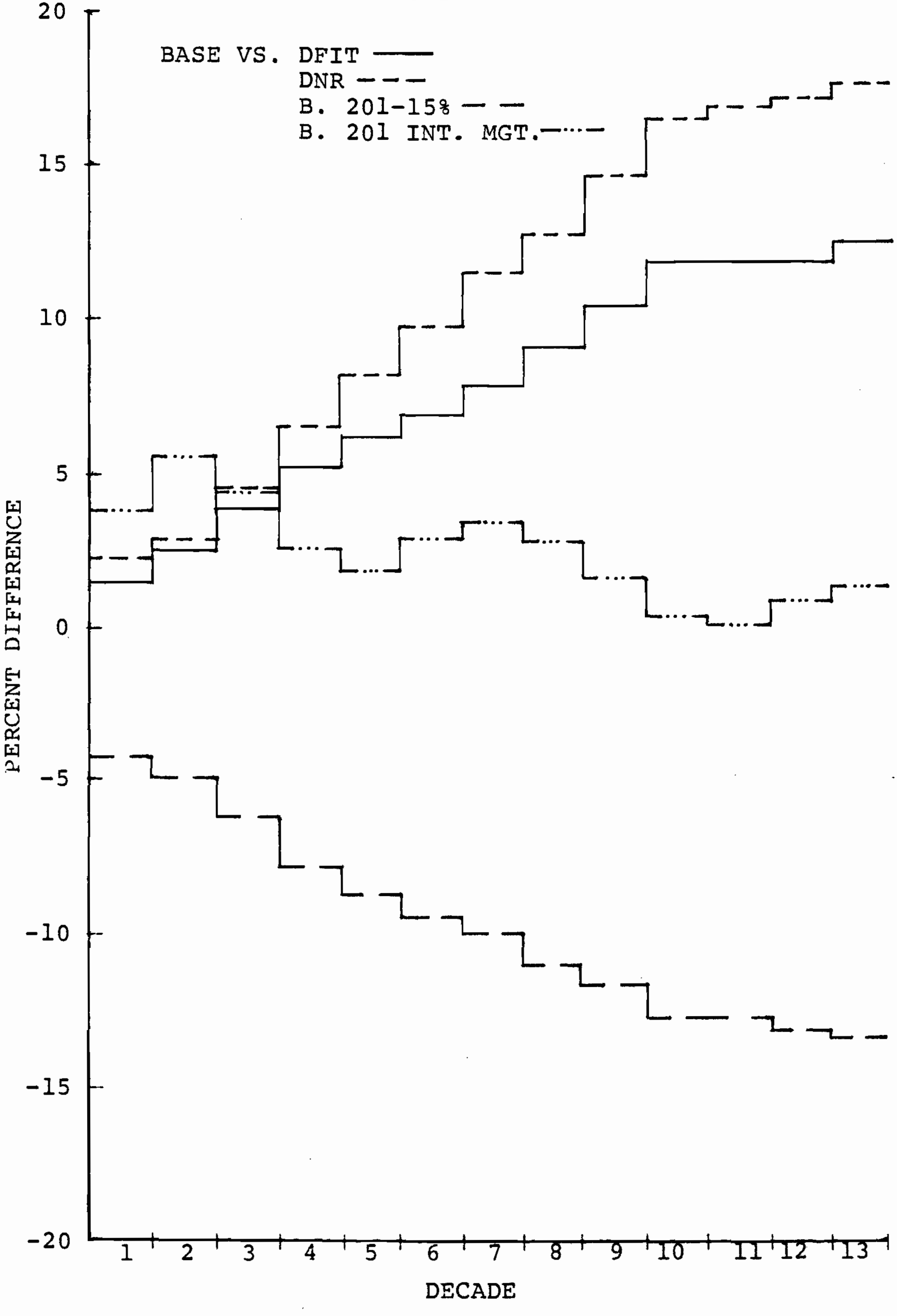

FIGURE A11. HARVEST LEVEL DIFFERENCE
INVENTORY 3

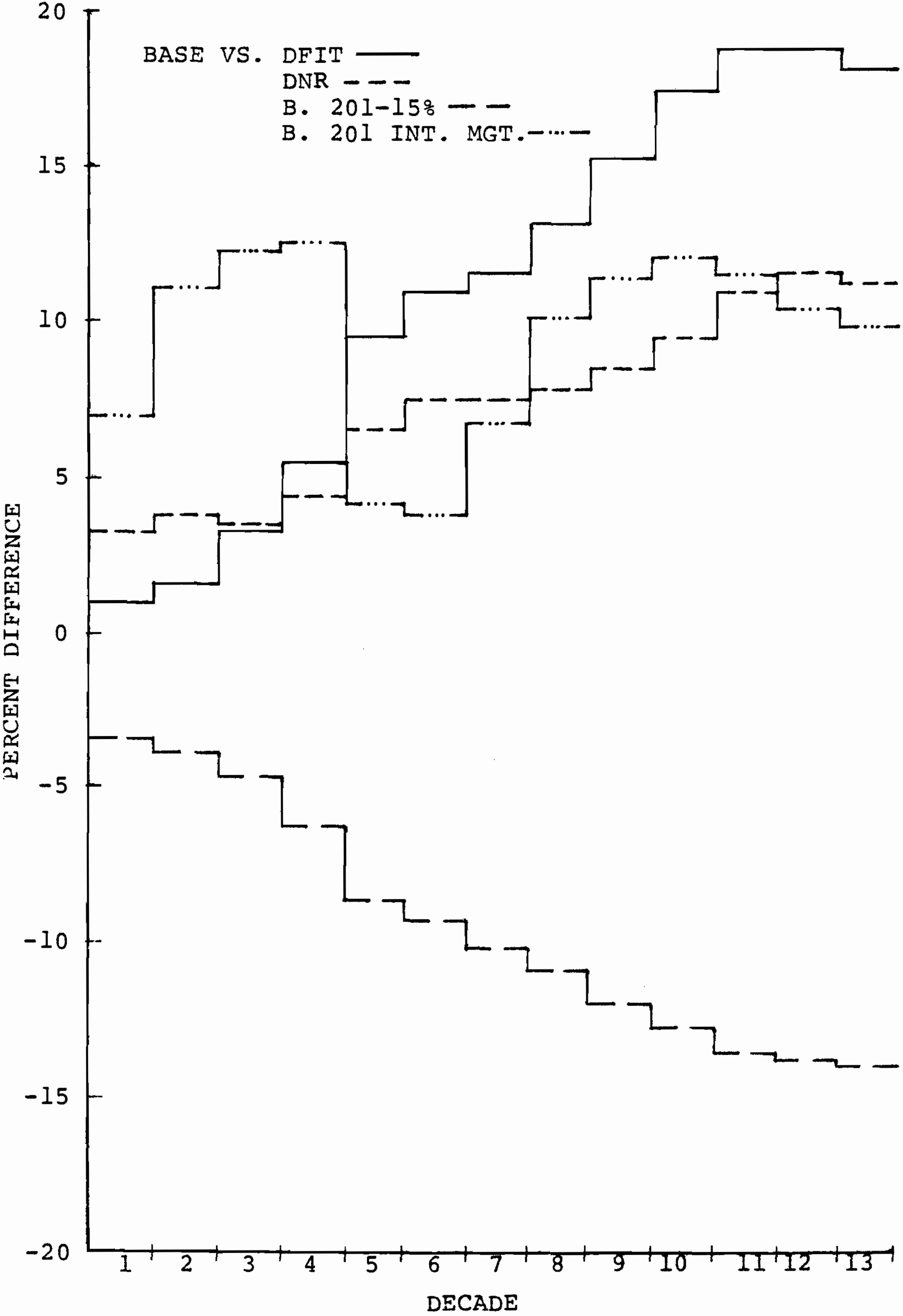

FIGURE A12. HARVEST LEVEL DIFFERENCE INVENTORY 4

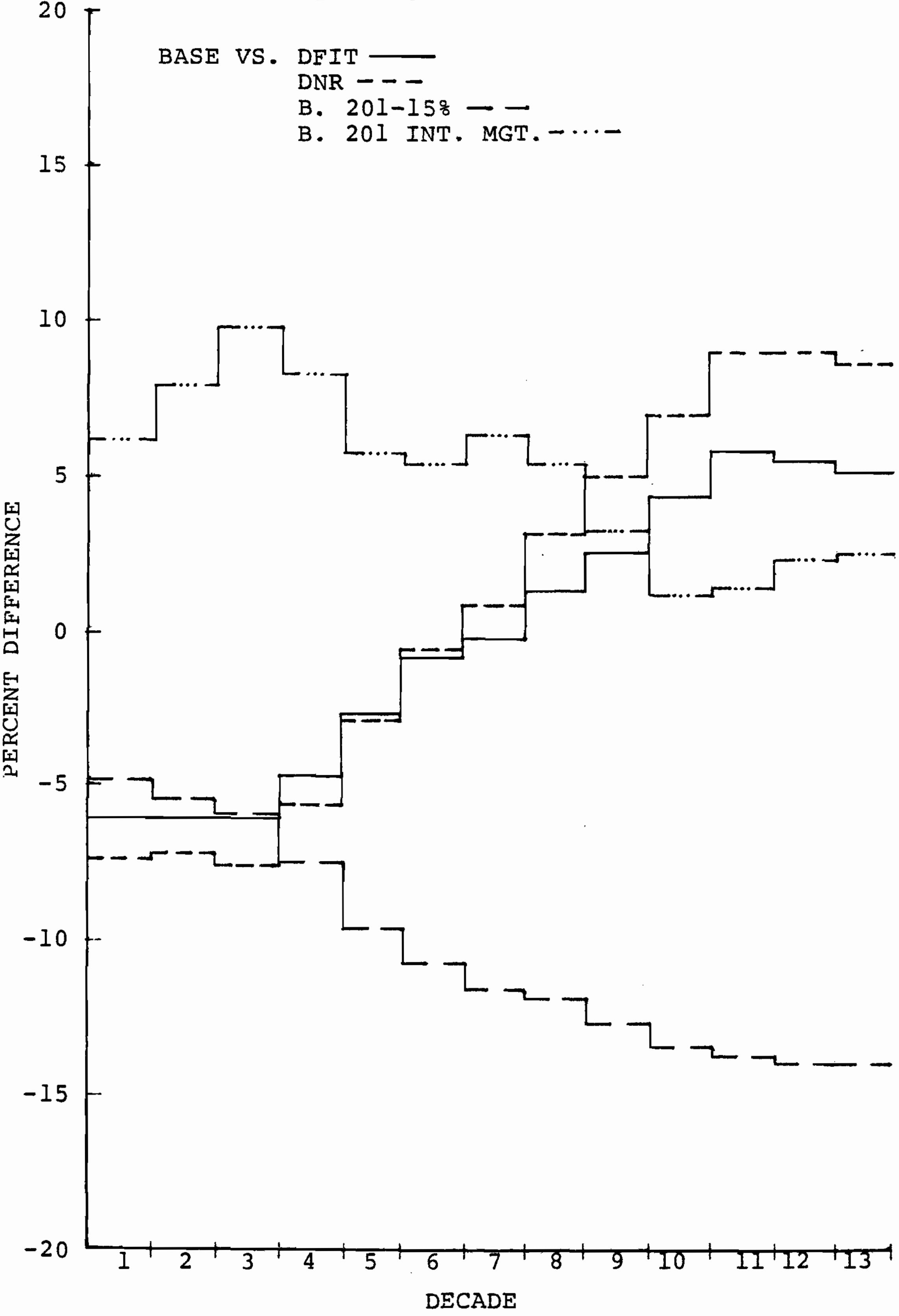

FIGURE A13. HARVEST LEVEL DIFFERENCE
INVENTORY 5

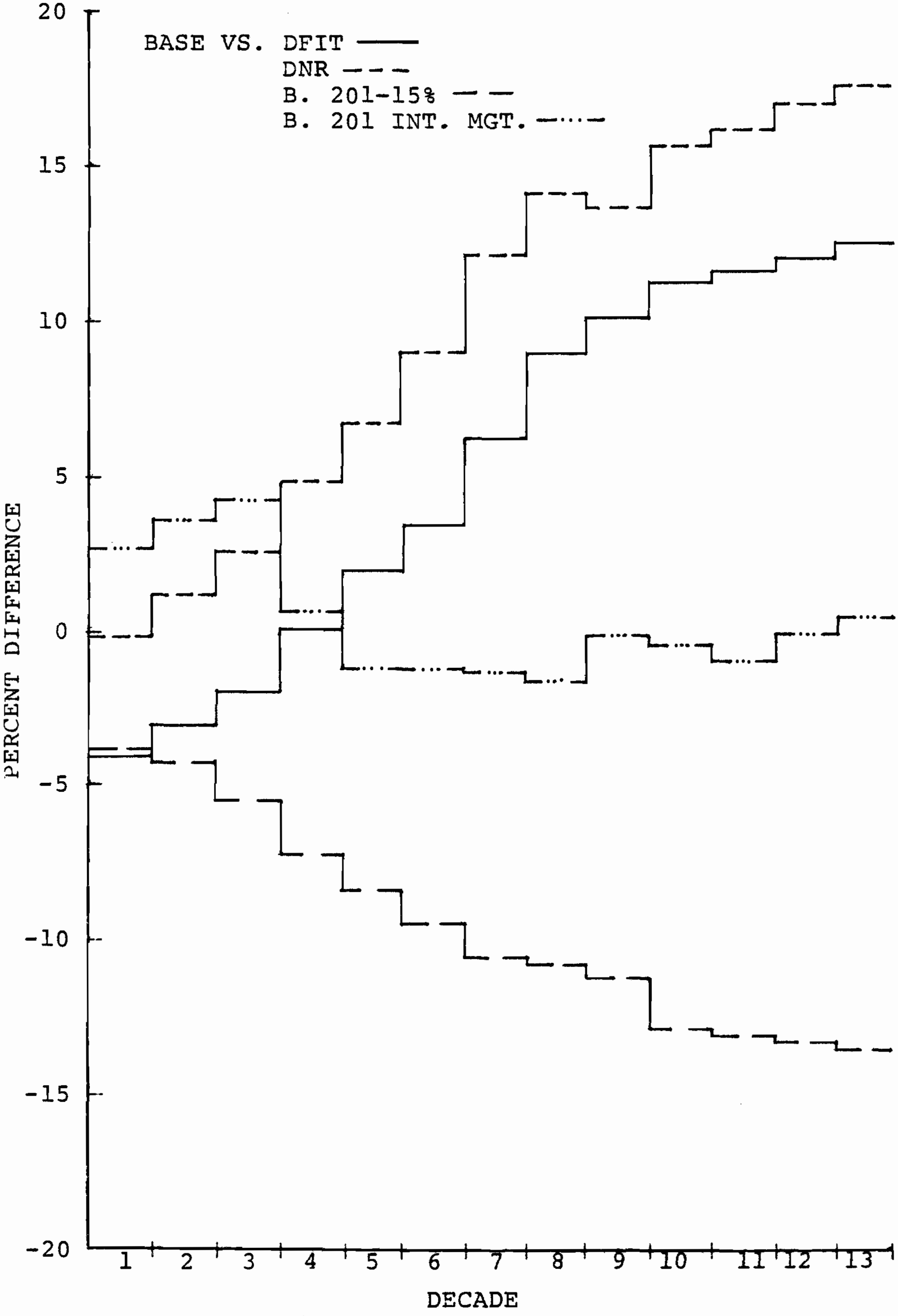

FIGURE A14. HARVEST LEVEL DIFFERENCE
INVENTORY 6

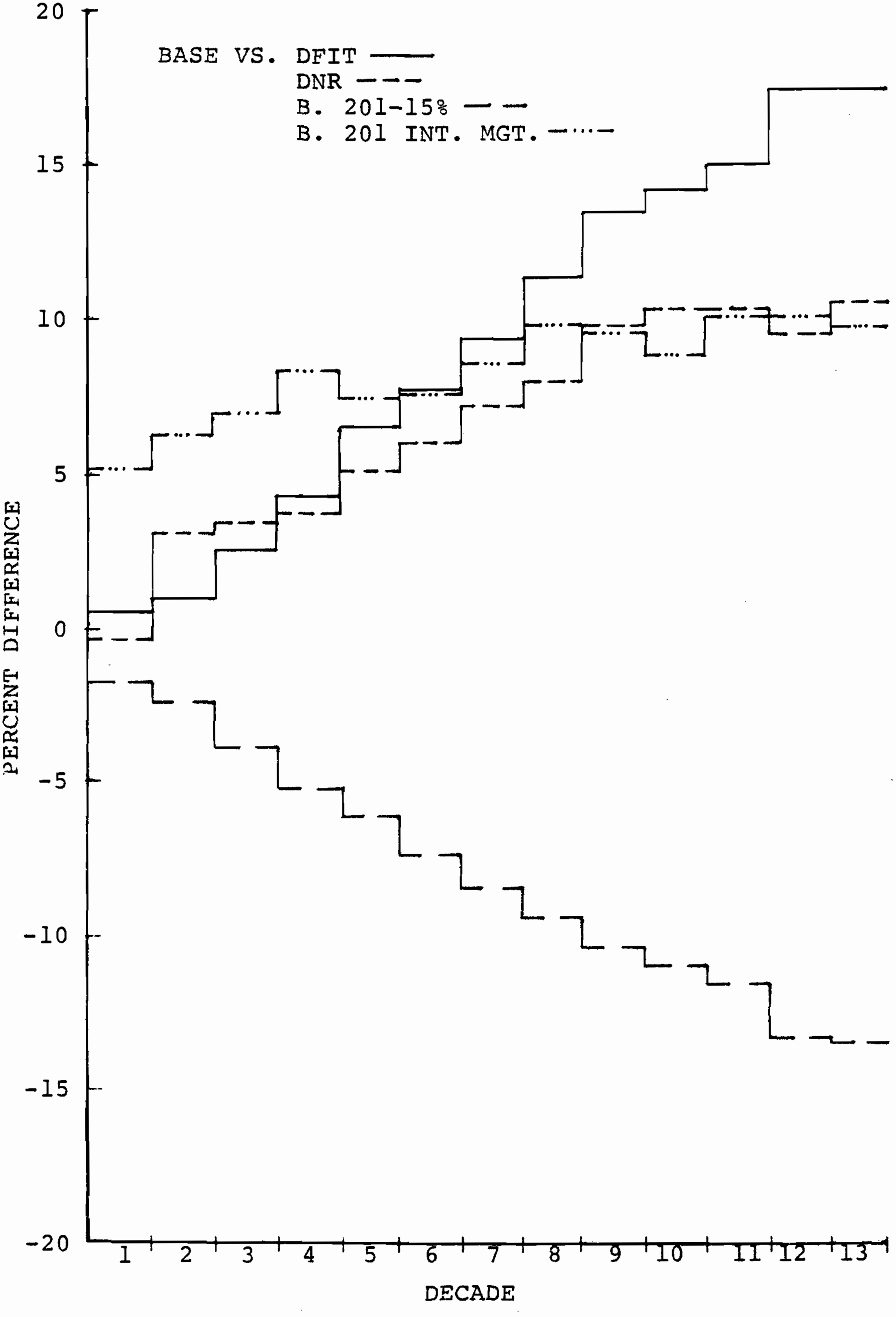

FIGURE A15. HARVEST LEVEL DIFFERENCE
INVENTORY 7

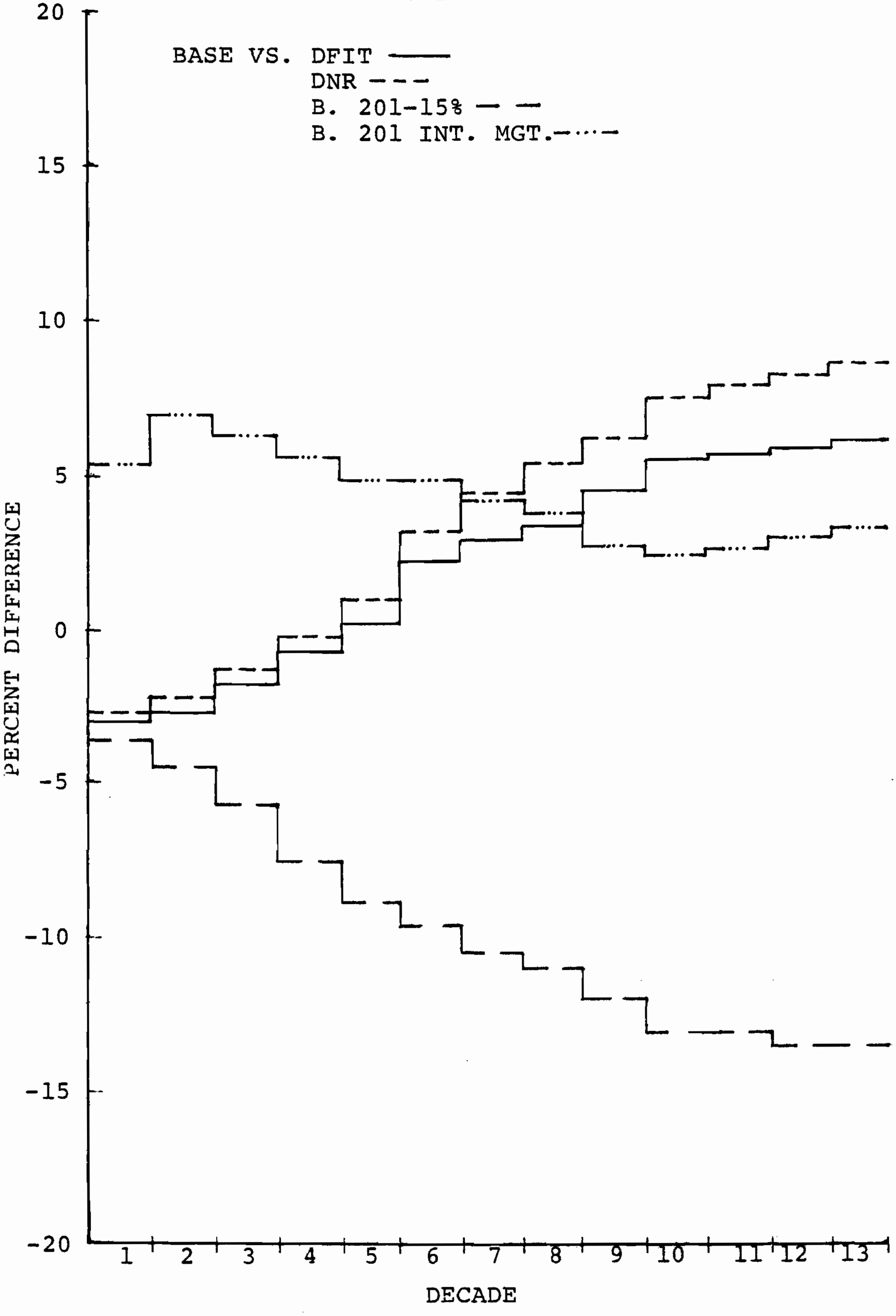

FIGURE A16. HARVEST LEVEL DIFFERENCE

INVENTORY 8

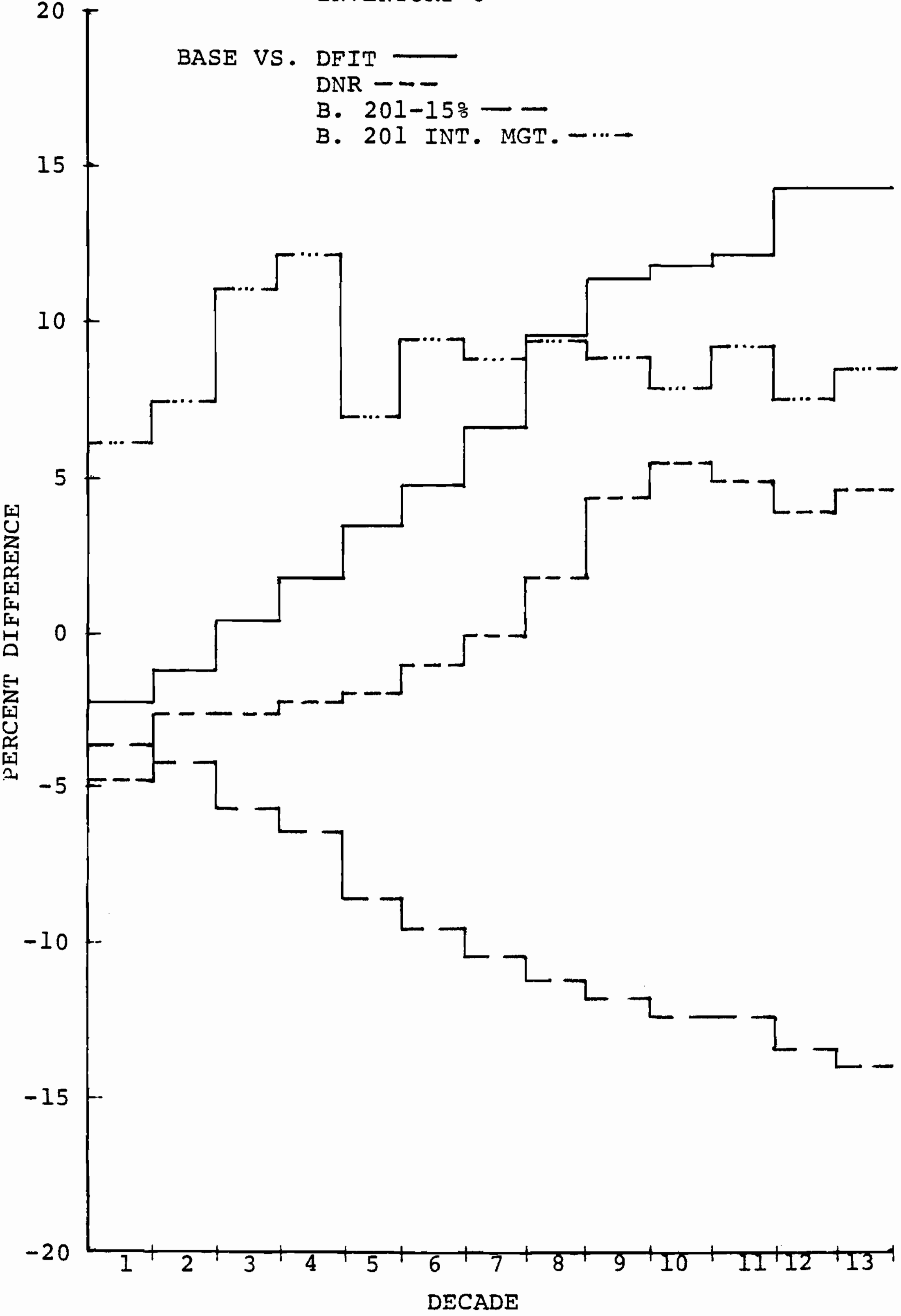

FIGURE A17. HARVEST LEVEL DIFFERENCE
INVENTORY 1

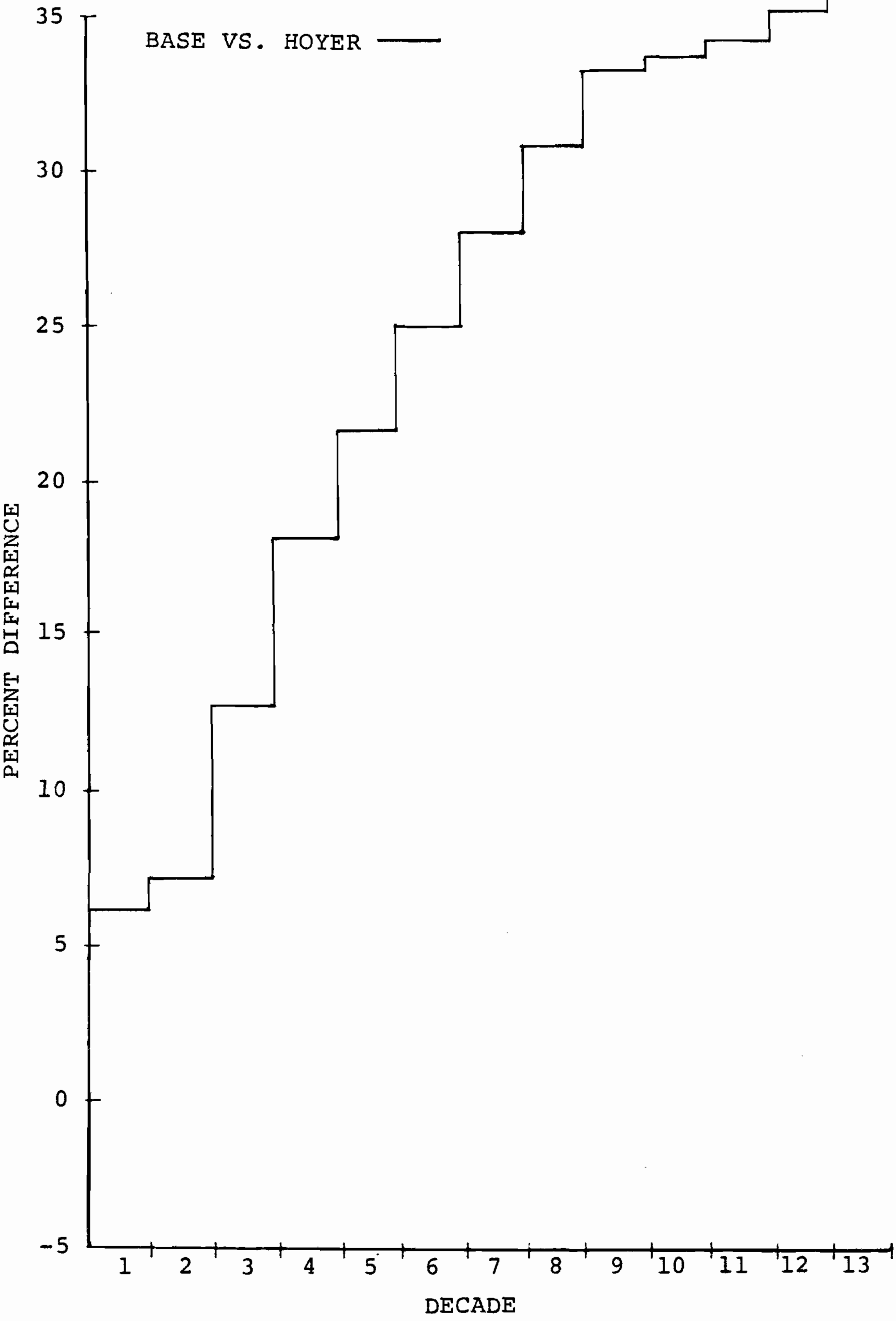

FIGURE A18. HARVEST LEVEL DIFFERENCE

INVENTORY 2

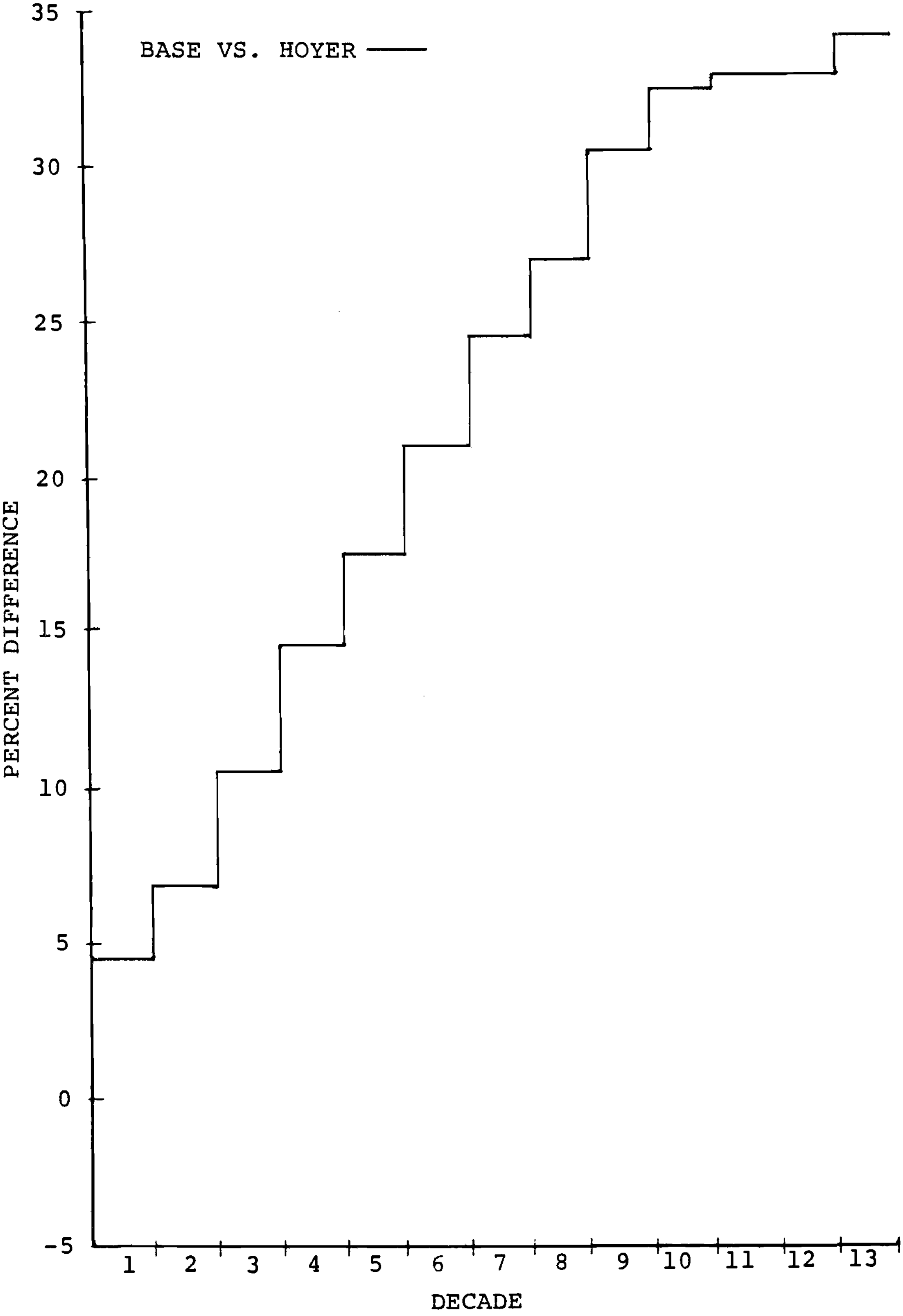

FIGURE A19. HARVEST LEVEL DIFFERENCE

INVENTORY 3

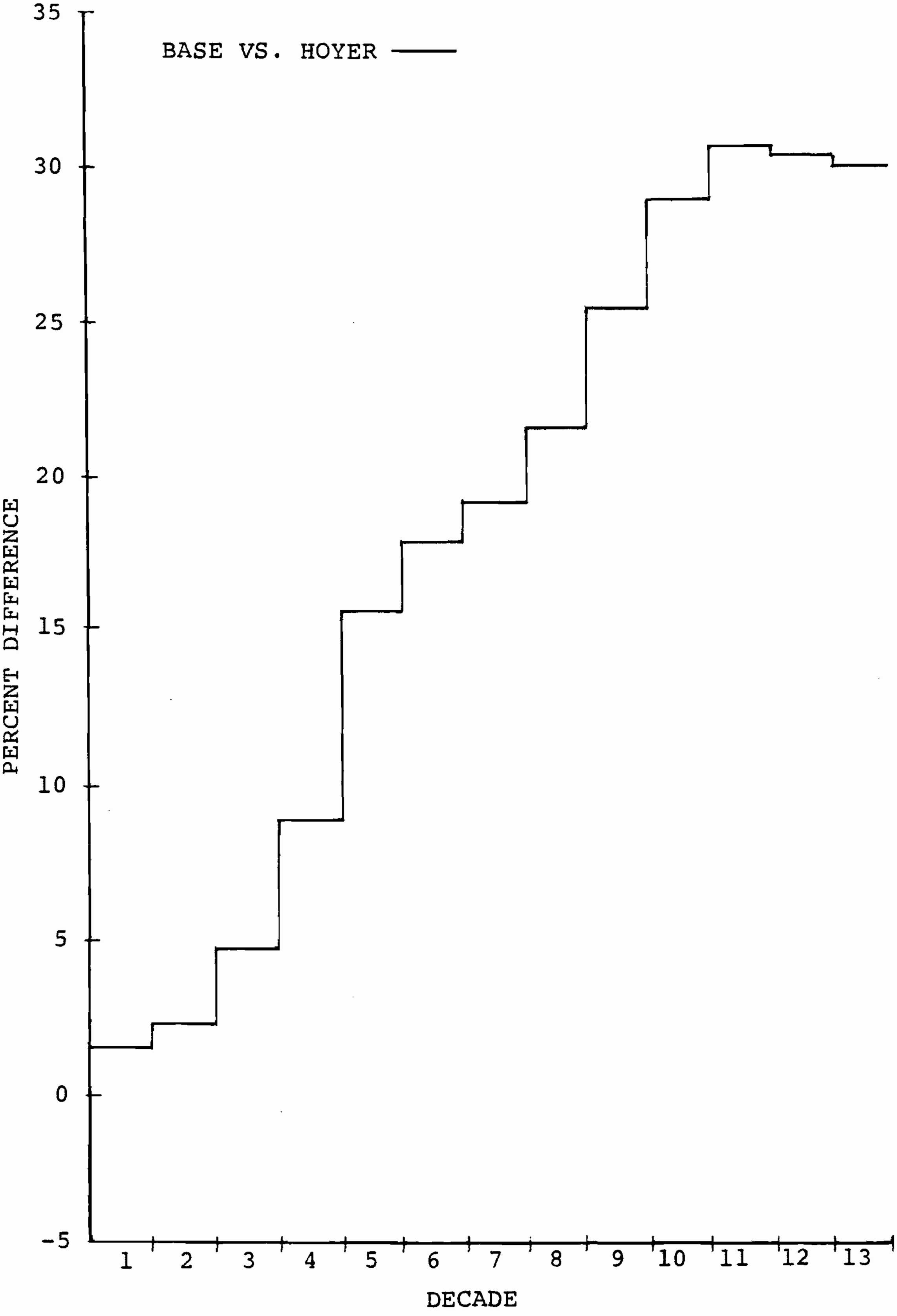

FIGURE A20. HARVEST LEVEL DIFFERENCE

INVENTORY 4

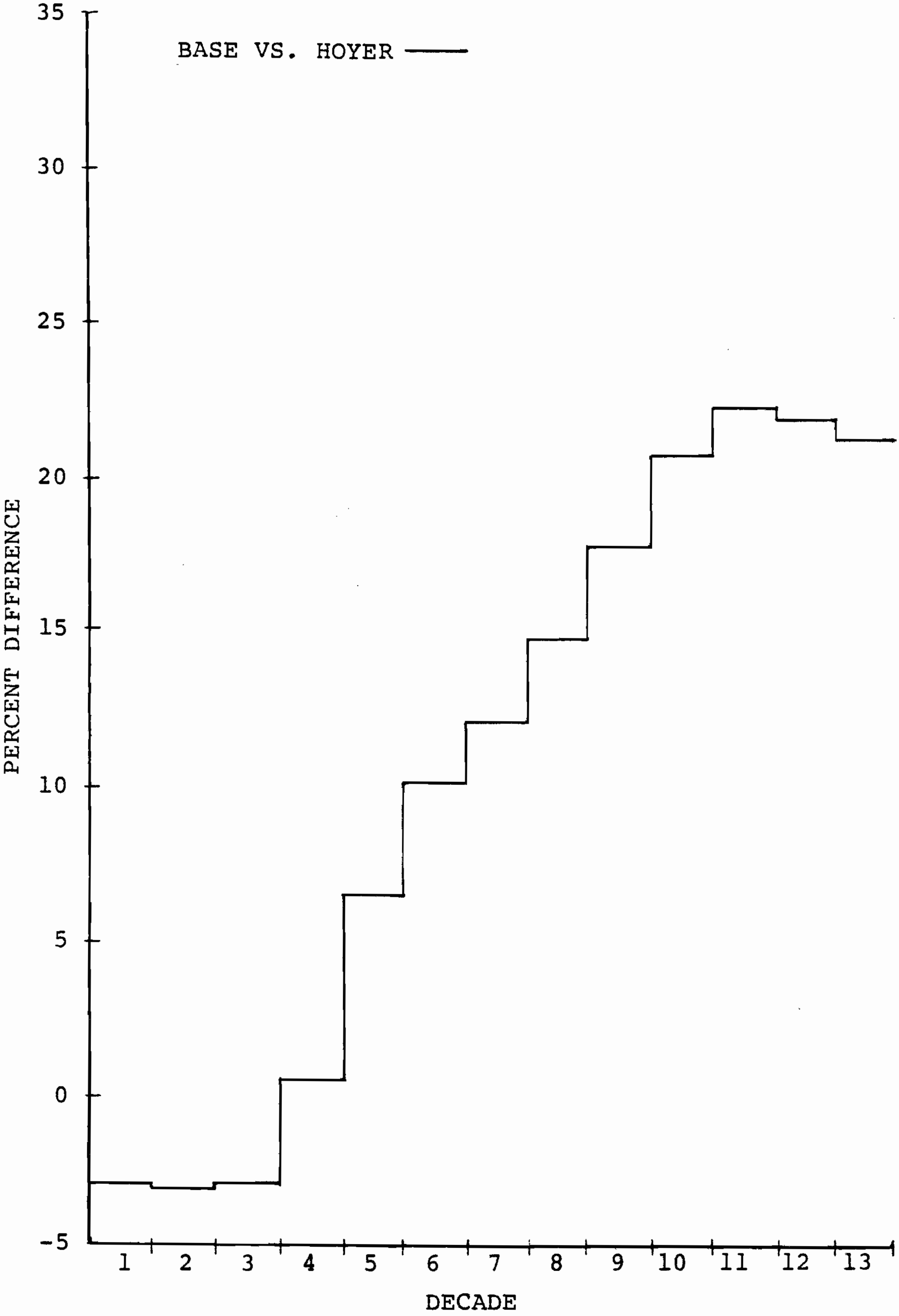

FIGURE A21. HARVEST LEVEL DIFFERENCE

INVENTORY 5

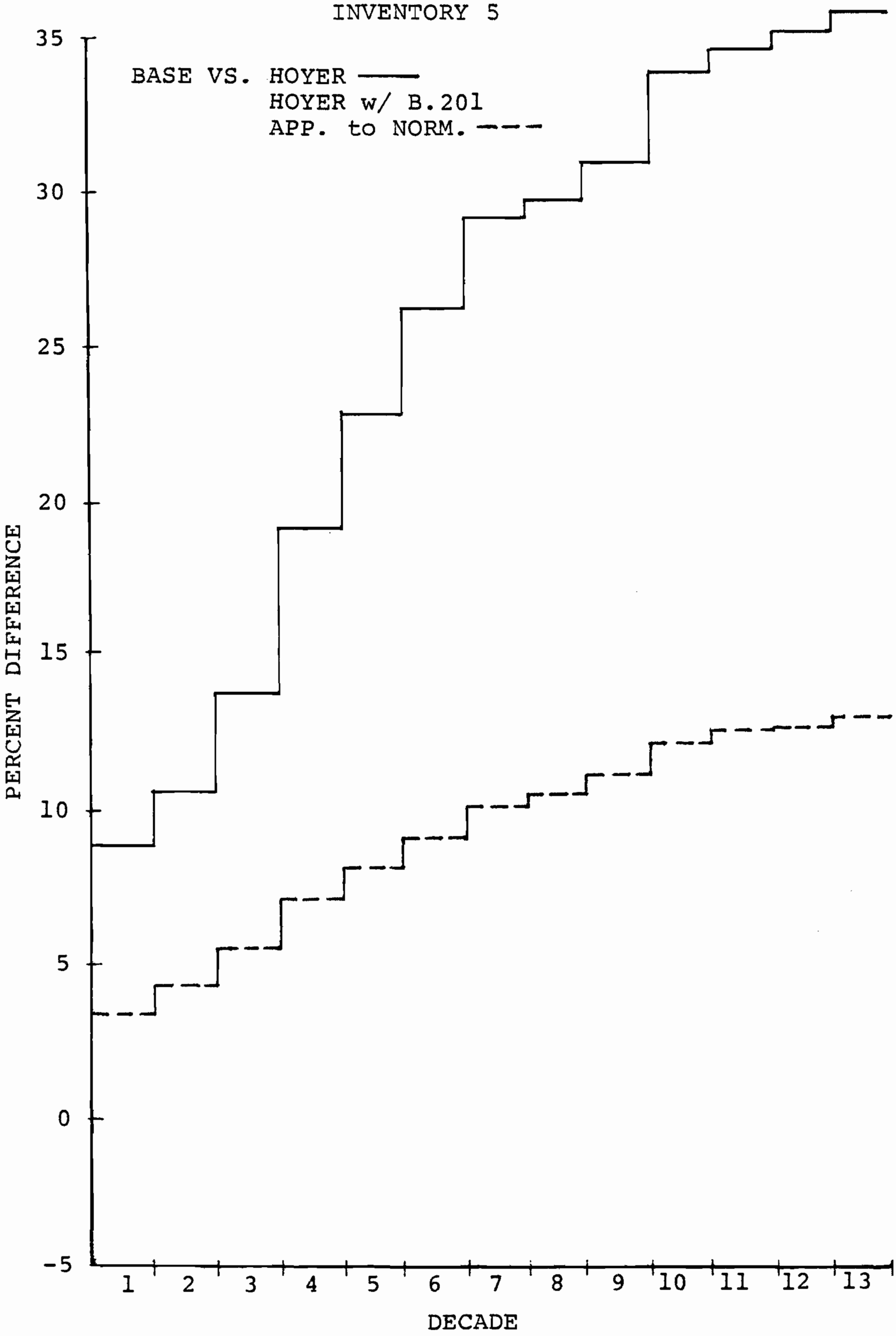

FIGURE A22. HARVEST LEVEL DIFFERENCE

INVENTORY 6

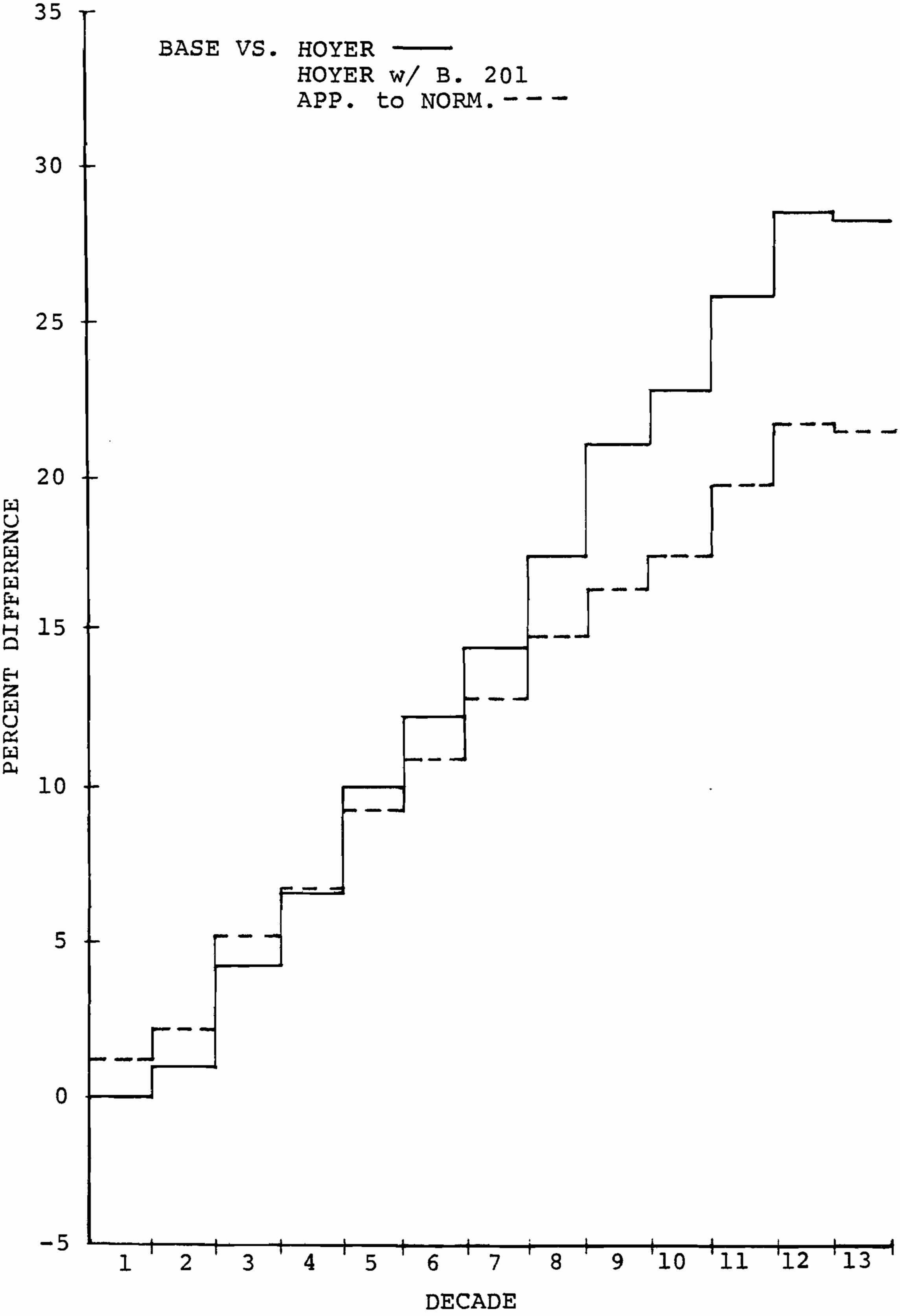

FIGURE A23. HARVEST LEVEL DIFFERENCE
INVENTORY 7

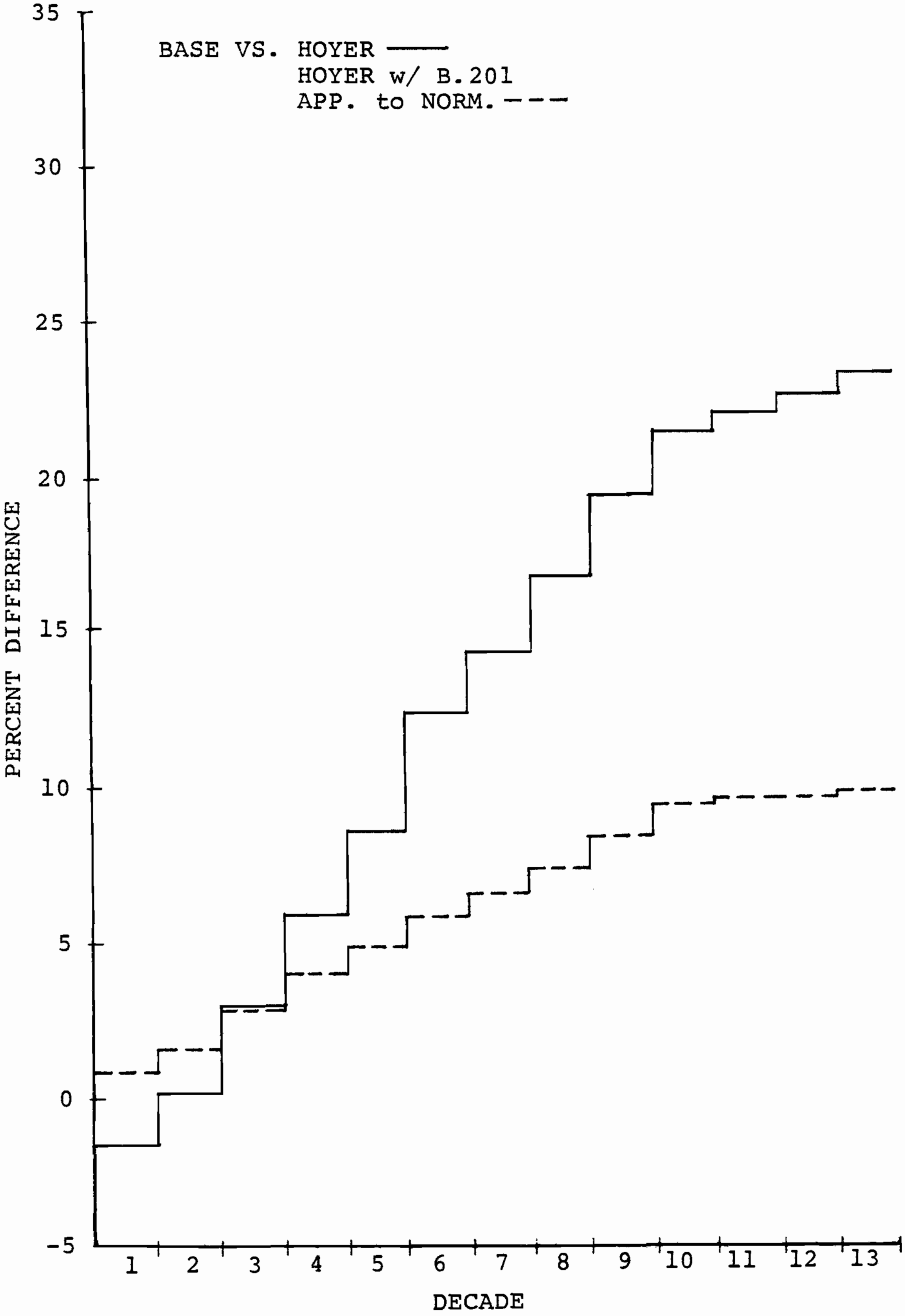

FIGURE A24. HARVEST LEVEL DIFFERENCE

INVENTORY 8

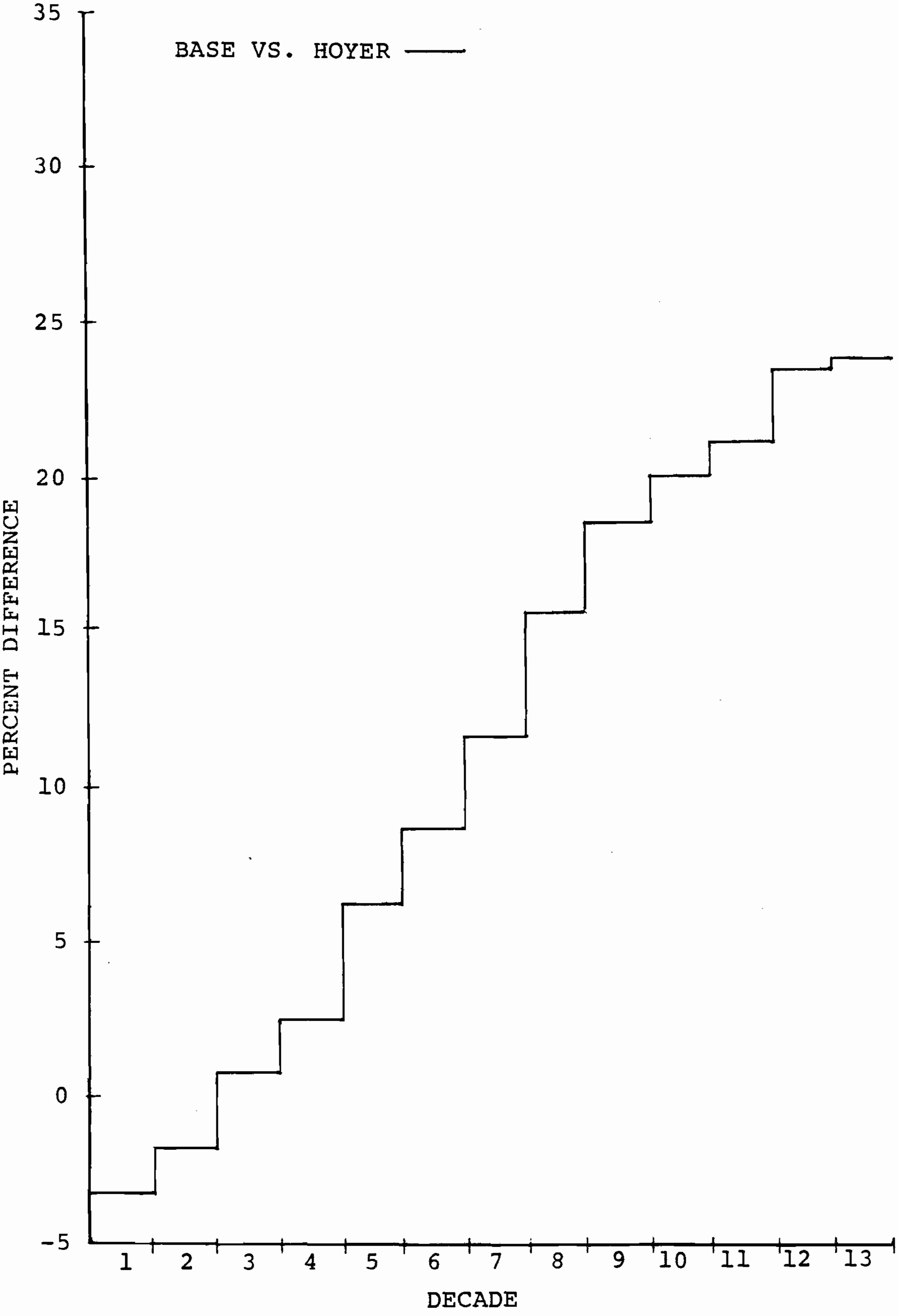

FIGURE A25. HARVEST LEVEL DIFFERENCE
INVENTORY 5

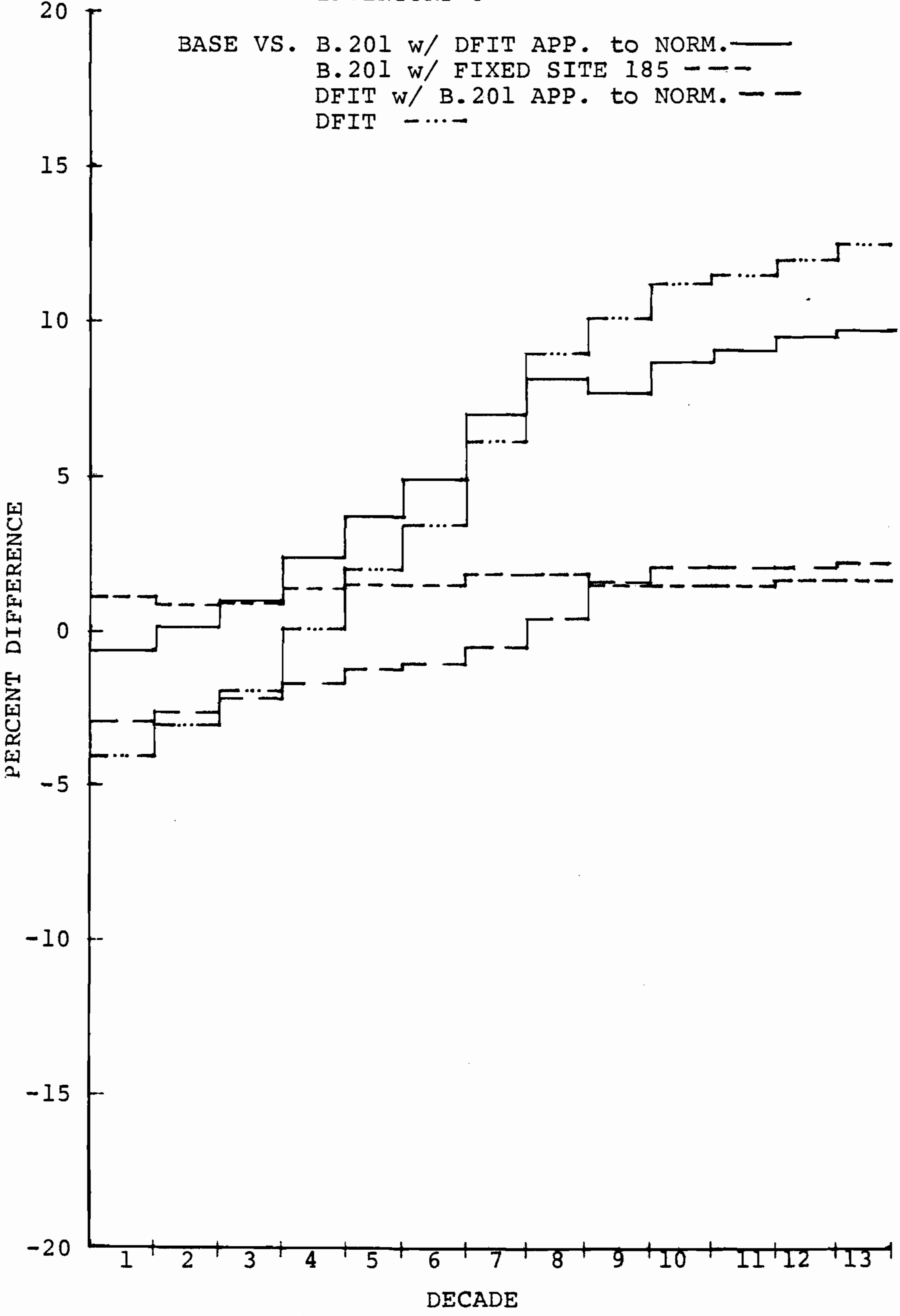

FIGURE A26. HARVEST LEVEL DIFFERENCE
INVENTORY 6

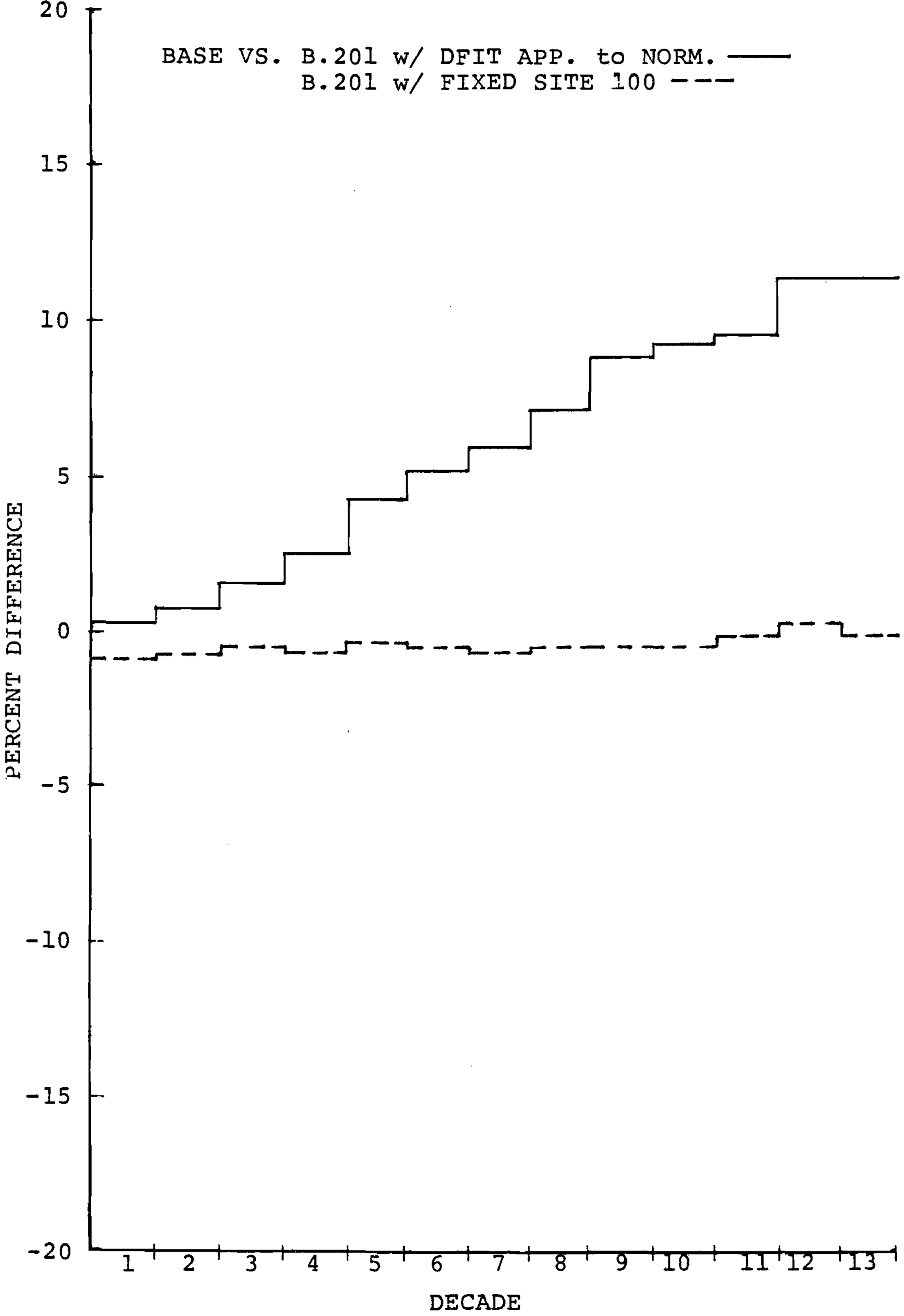

FIGURE A27. HARVEST LEVEL DIFFERENCE

INVENTORY 7

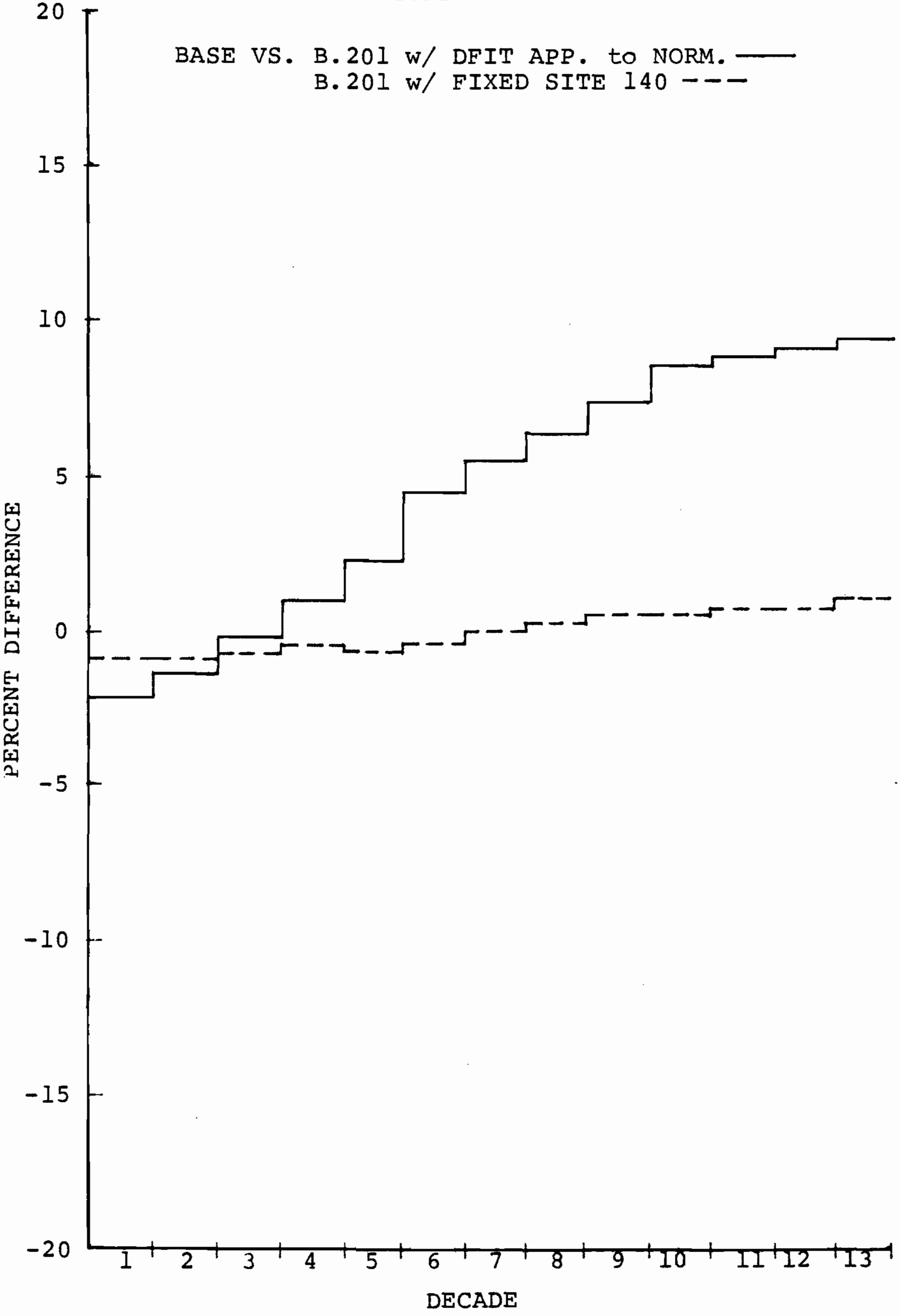

FIGURE A28. HARVEST LEVEL DIFFERENCE
INVENTORY 5

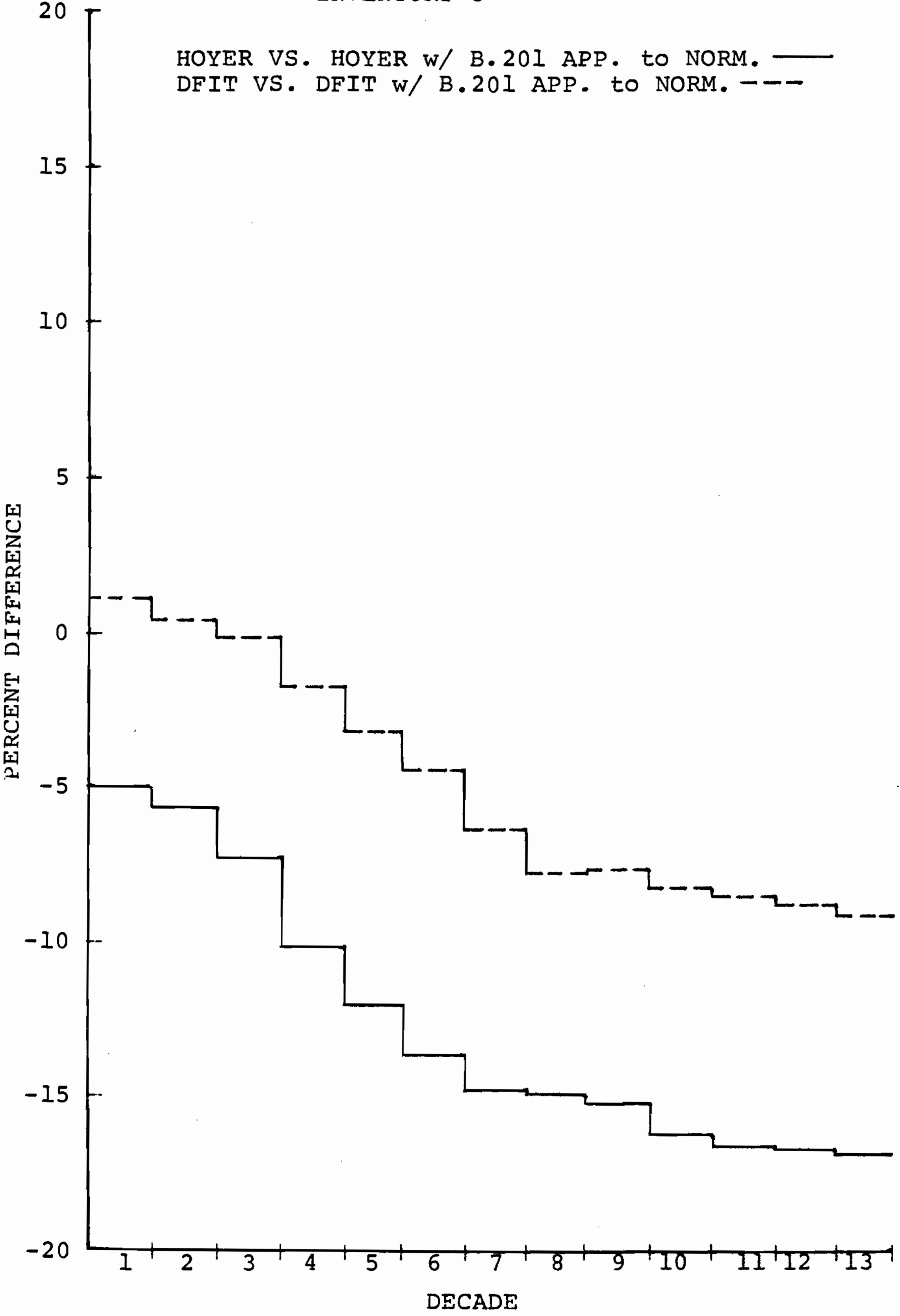

FIGURE A29. HARVEST LEVEL DIFFERENCE
INVENTORY 6

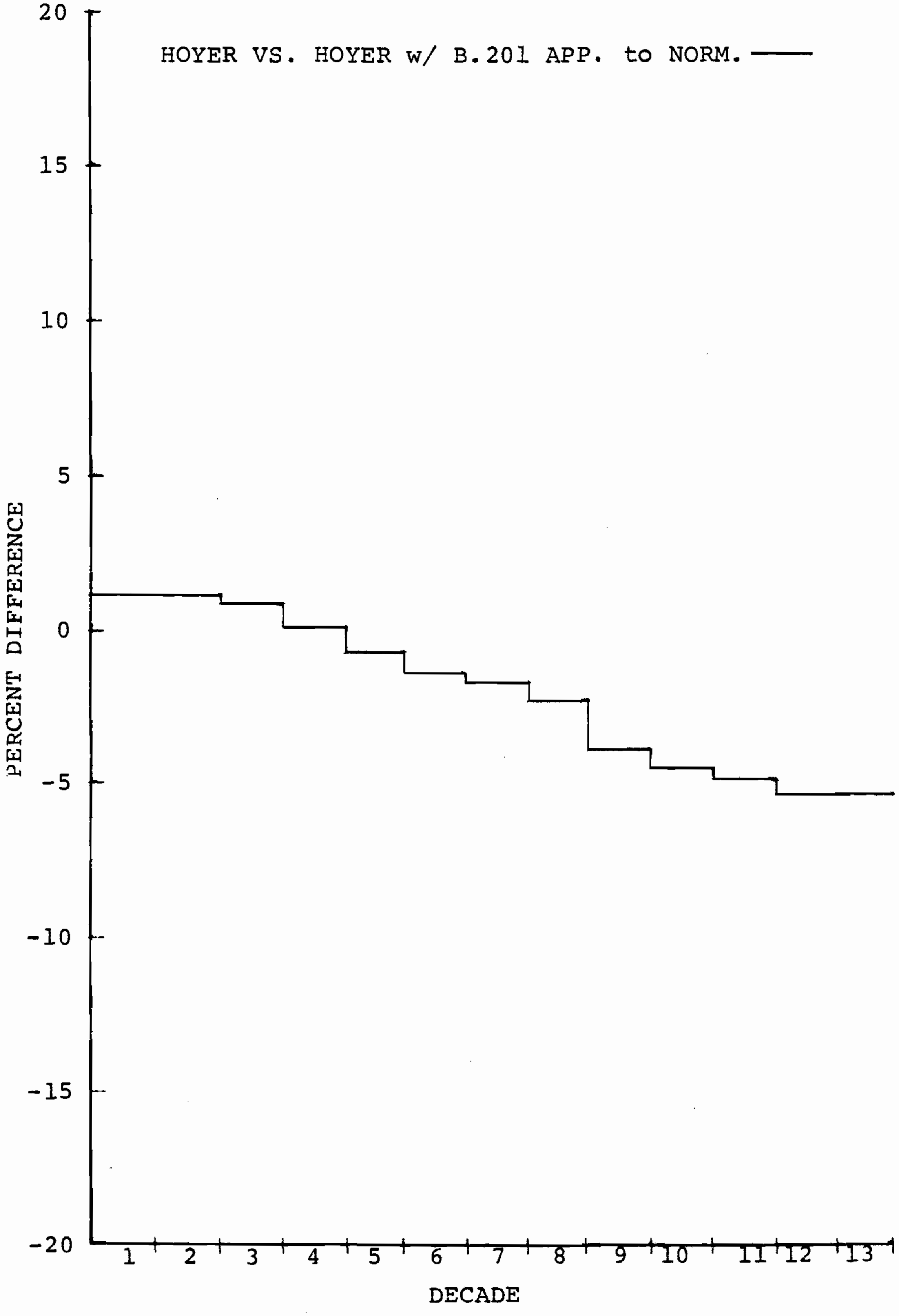

FIGURE A30. HARVEST LEVEL DIFFERENCE
INVENTORY 7

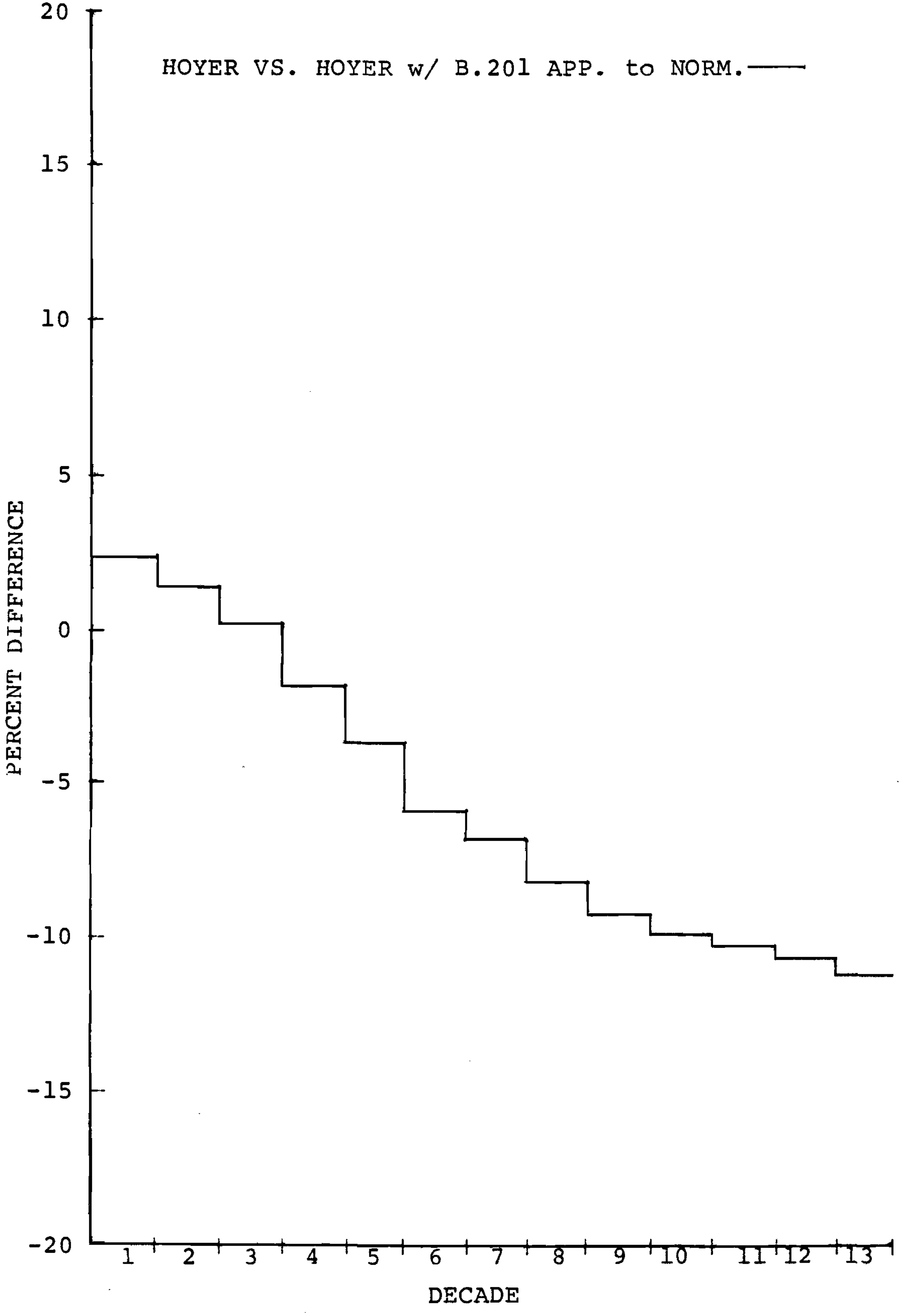

FIGURE A31. HARVEST LEVEL DIFFERENCE
INVENTORY 1

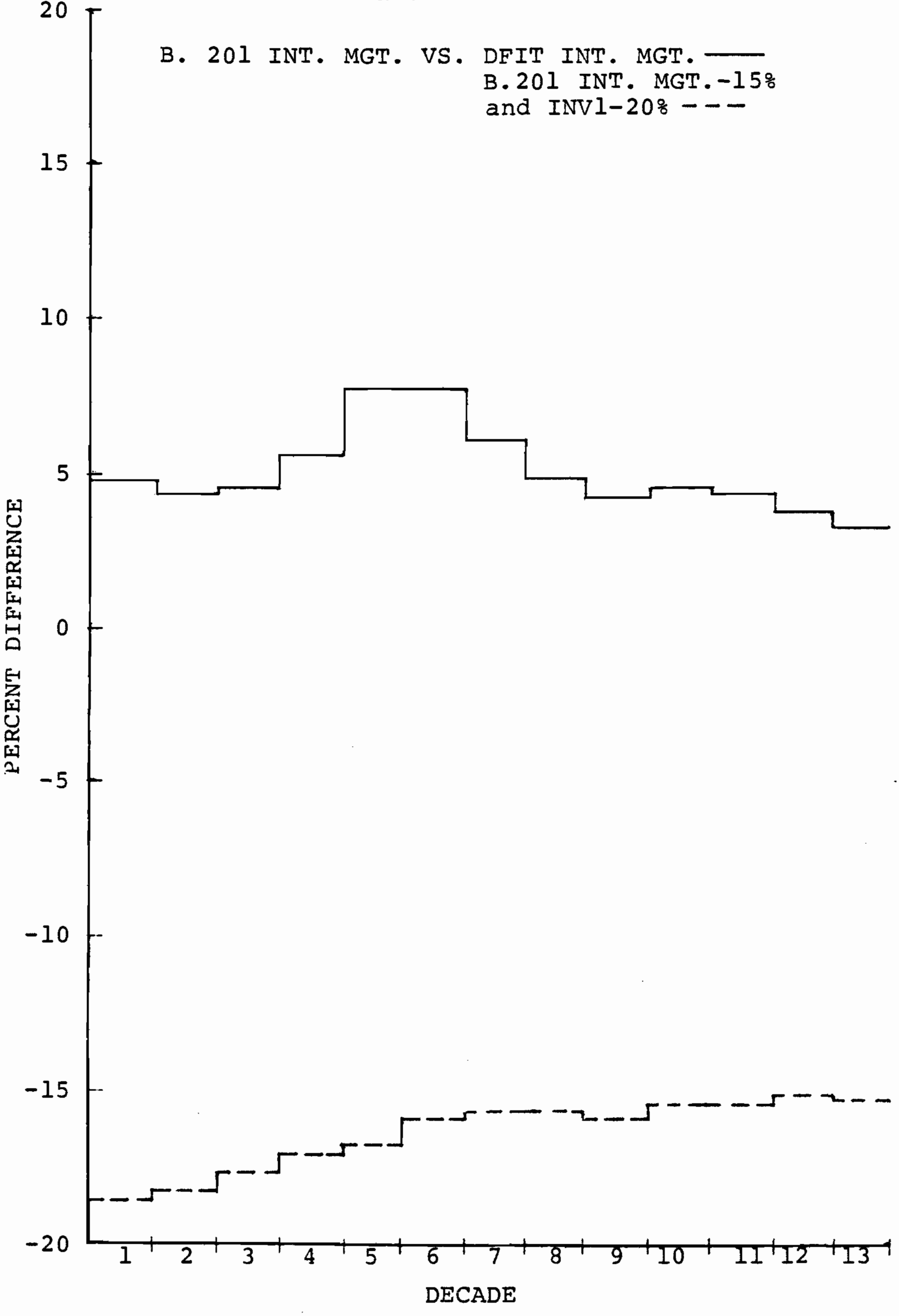

FIGURE A32. HARVEST LEVEL DIFFERENCE
INVENTORY 2

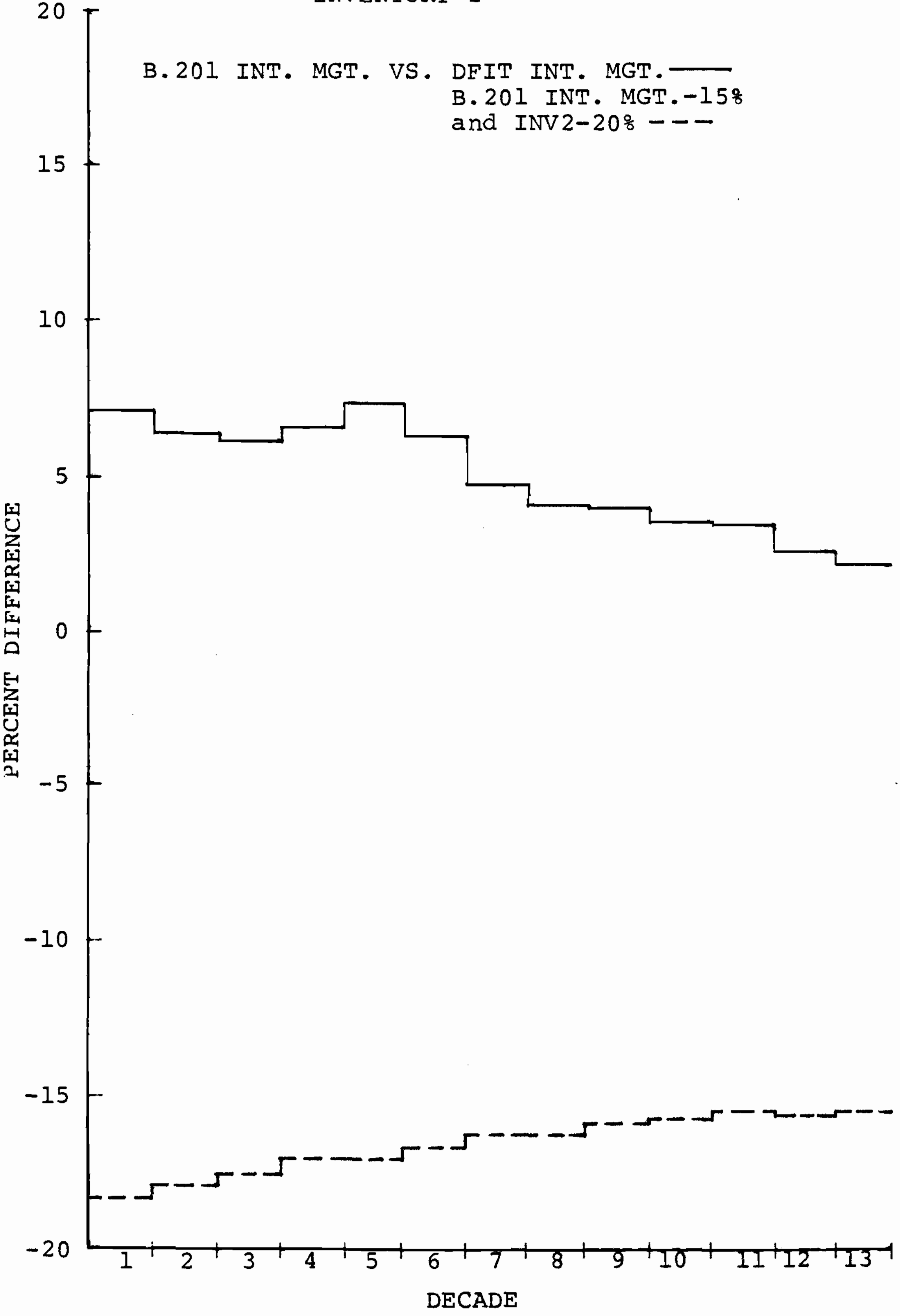

FIGURE A33. HARVEST LEVEL DIFFERENCE
INVENTORY 3

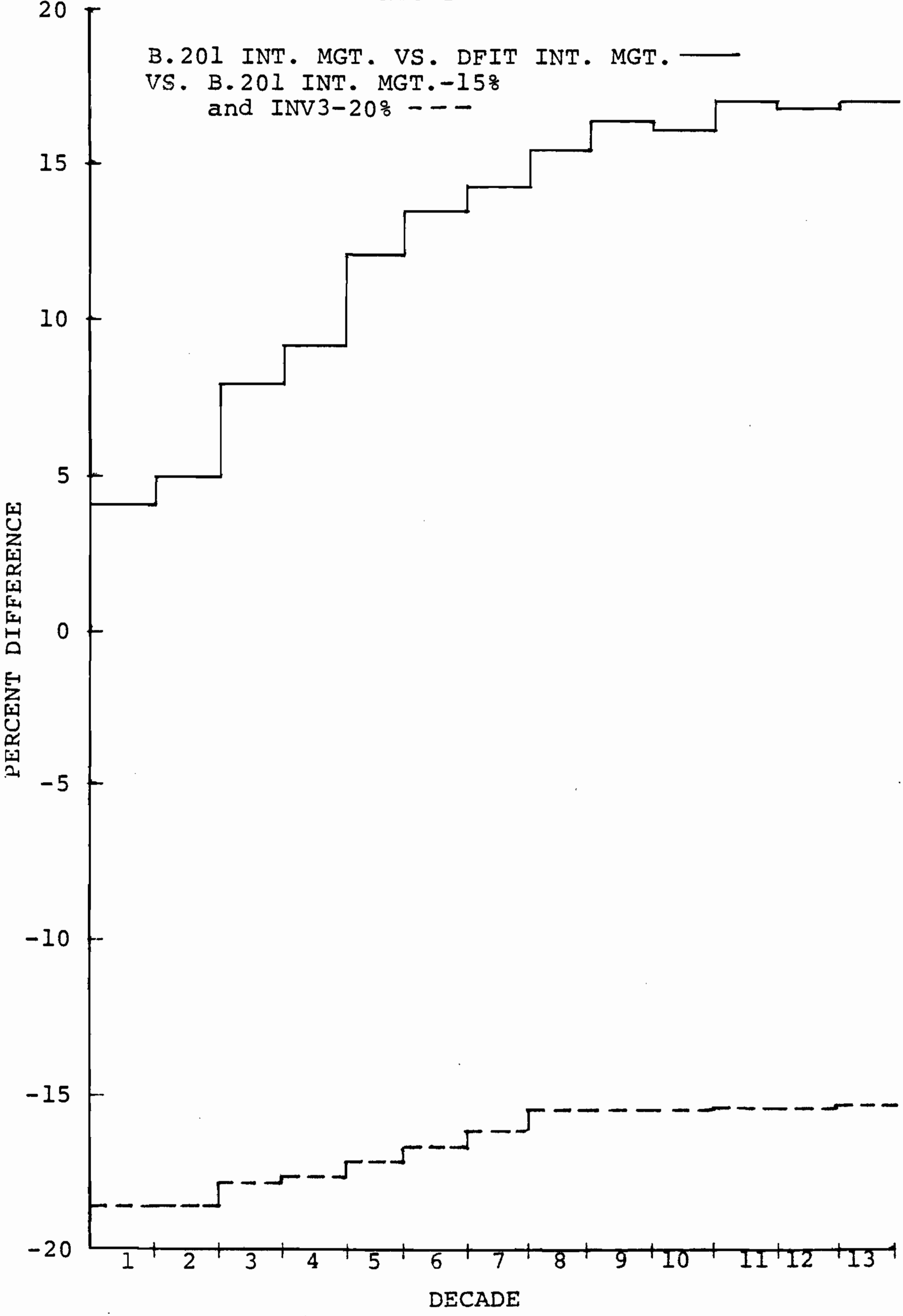

FIGURE A34. HARVEST LEVEL DIFFERENCE
INVENTORY 4

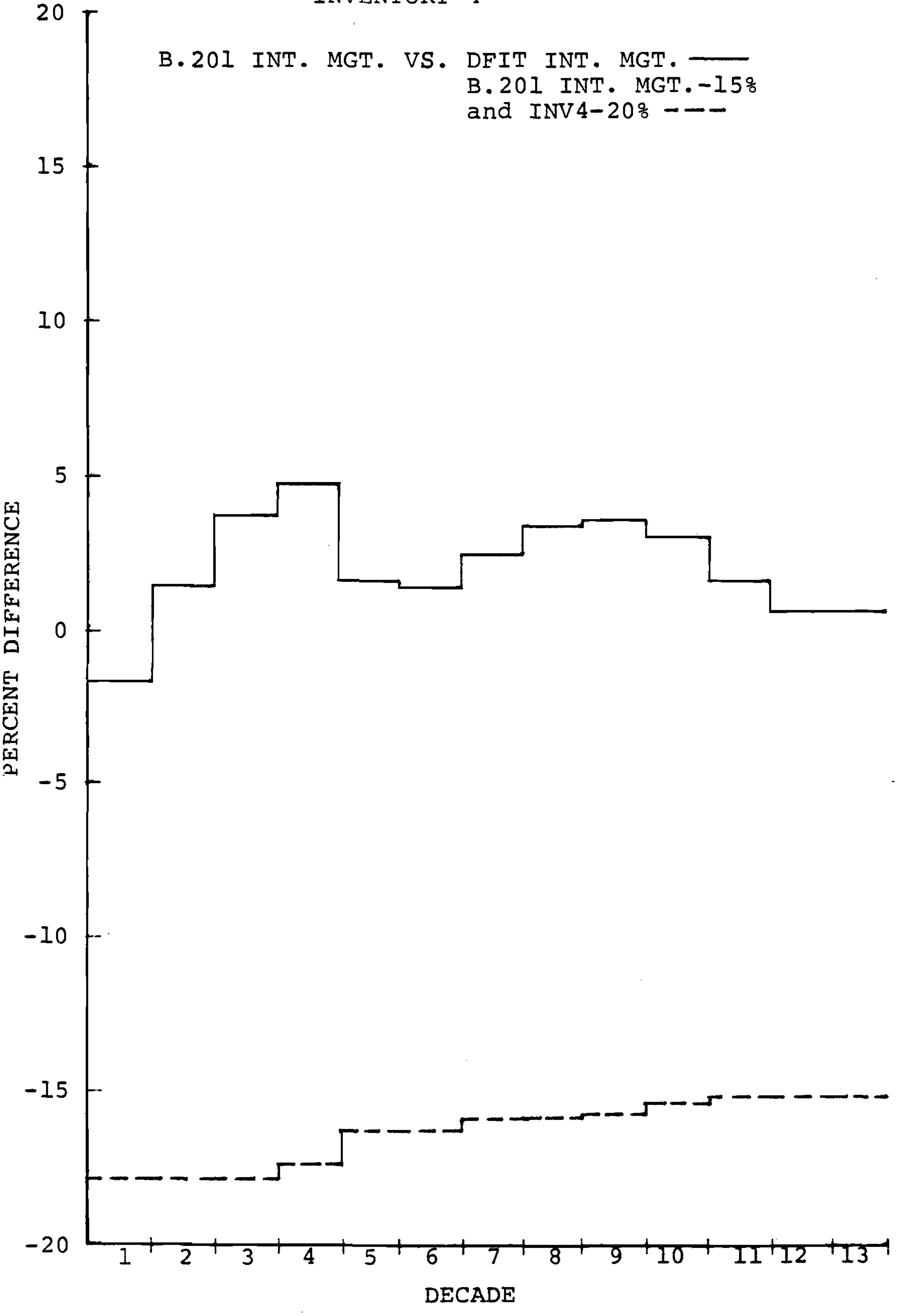

FIGURE A35. HARVEST LEVEL DIFFERENCE

INVENTORY 5

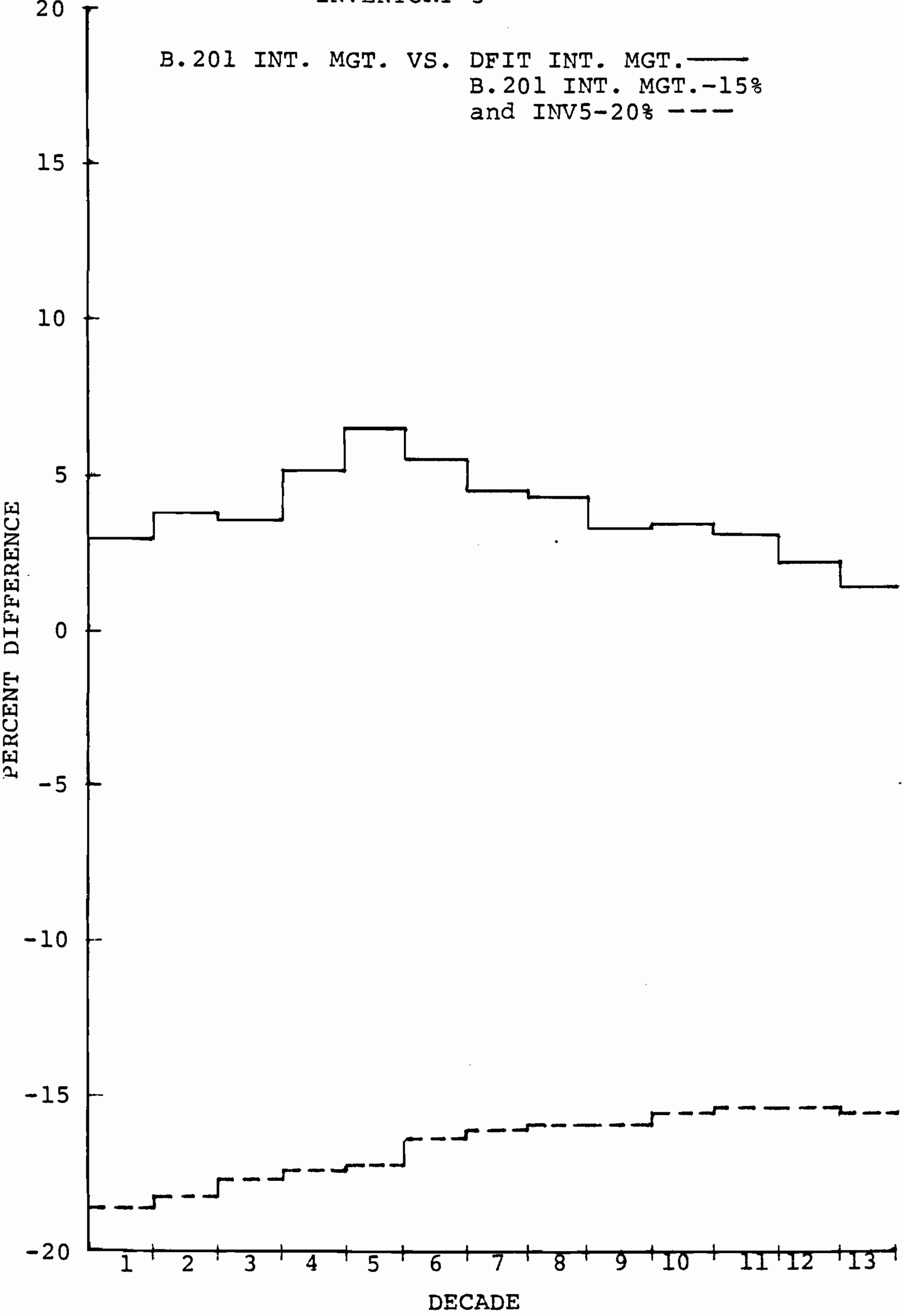

FIGURE A36. HARVEST LEVEL DIFFERENCE
INVENTORY 6

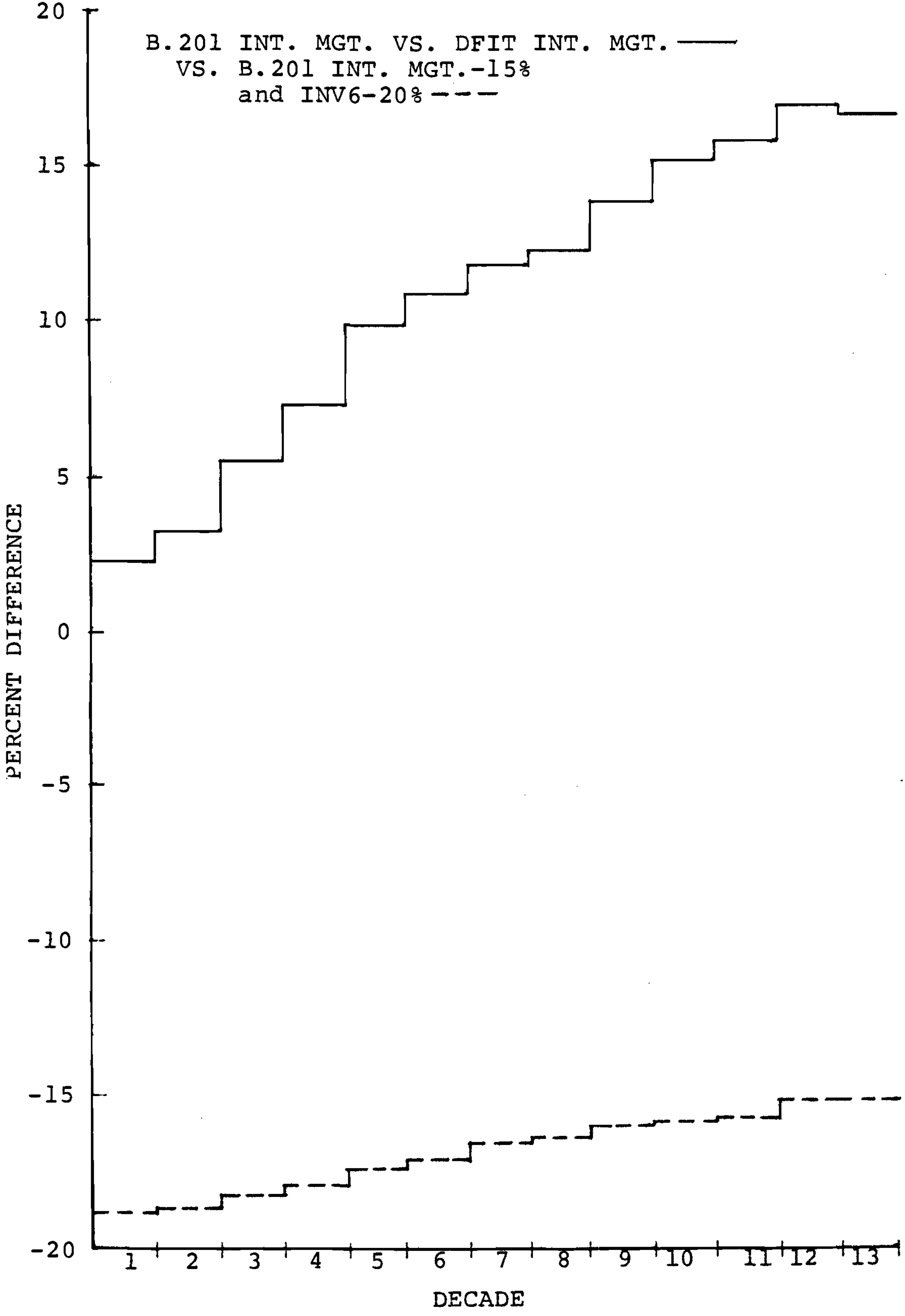

FIGURE A37. HARVEST LEVEL DIFFERENCE
INVENTORY 7

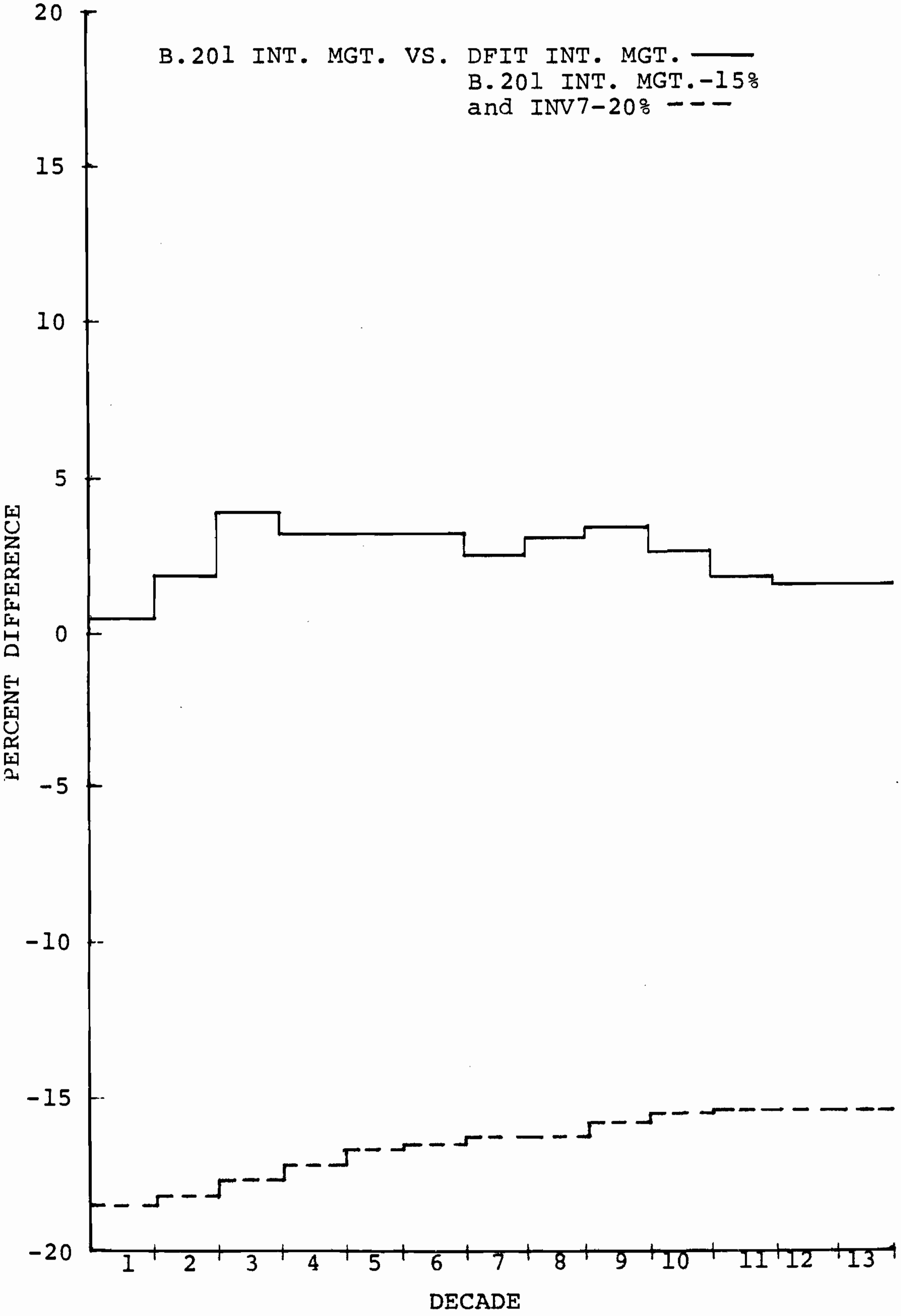

FIGURE A38. HARVEST LEVEL DIFFERENCE
INVENTORY 8

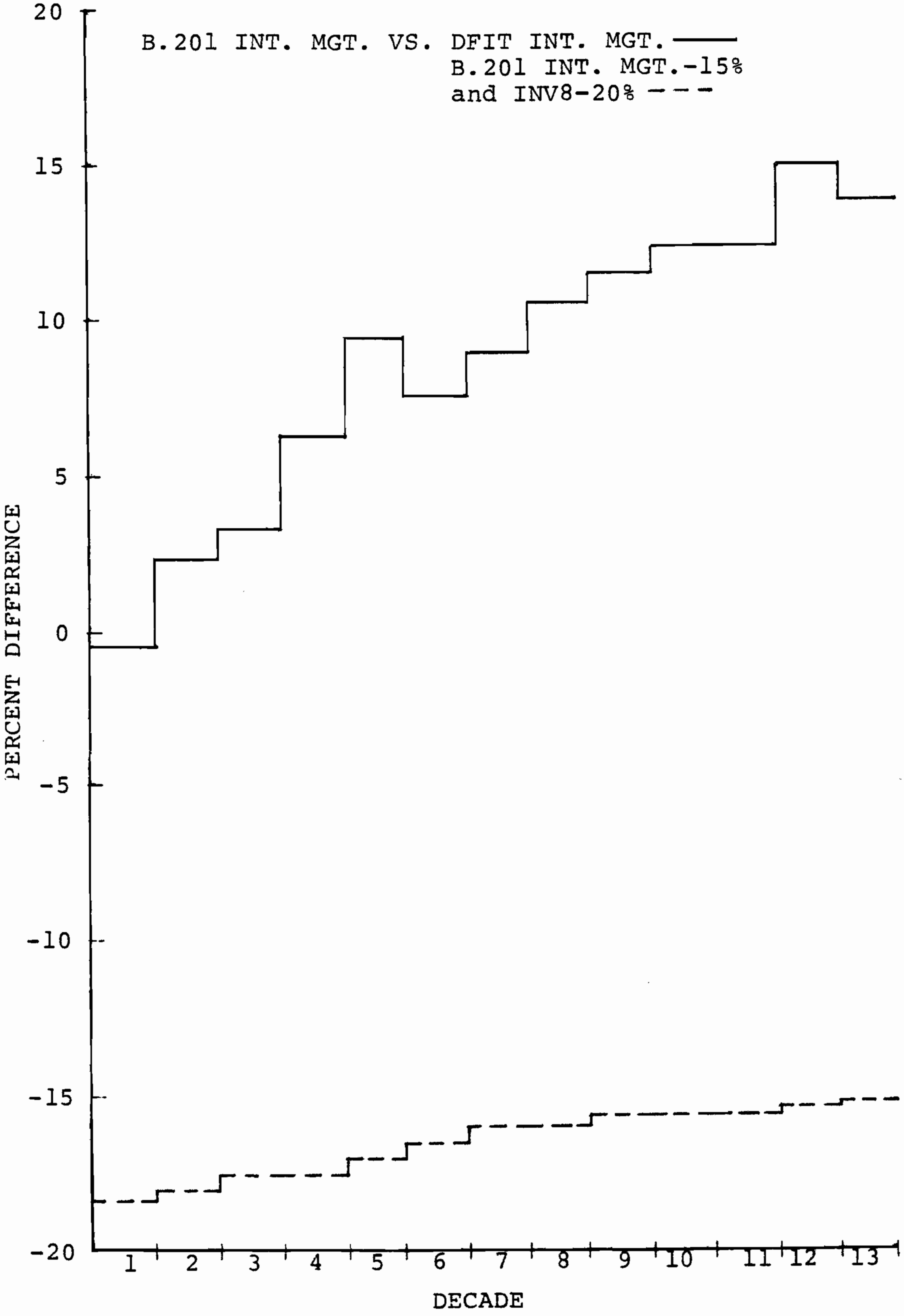

FIGURE A39. HARVEST LEVEL DIFFERENCE
INVENTORY 1

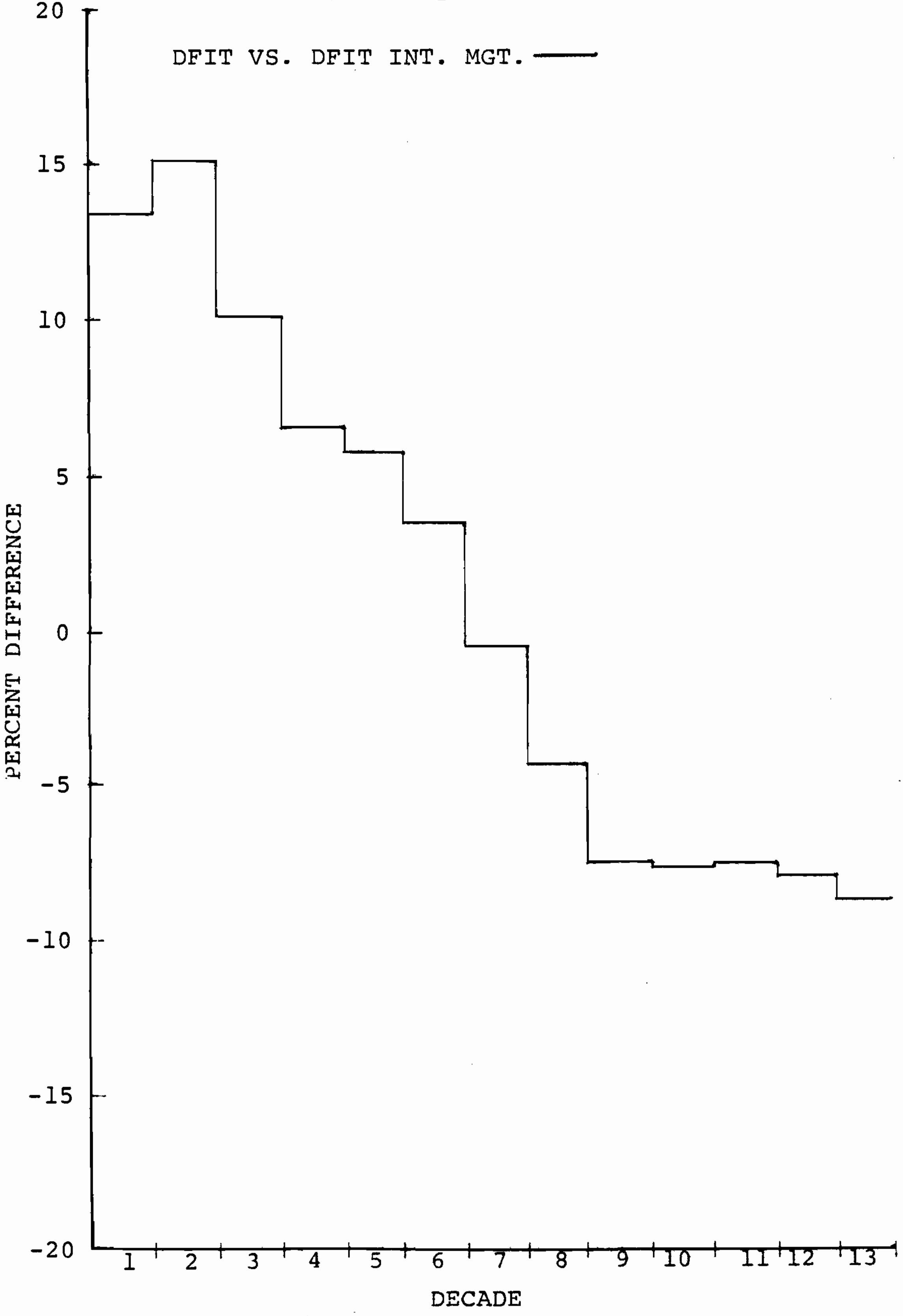

FIGURE A40. HARVEST LEVEL DIFFERENCE
INVENTORY 2

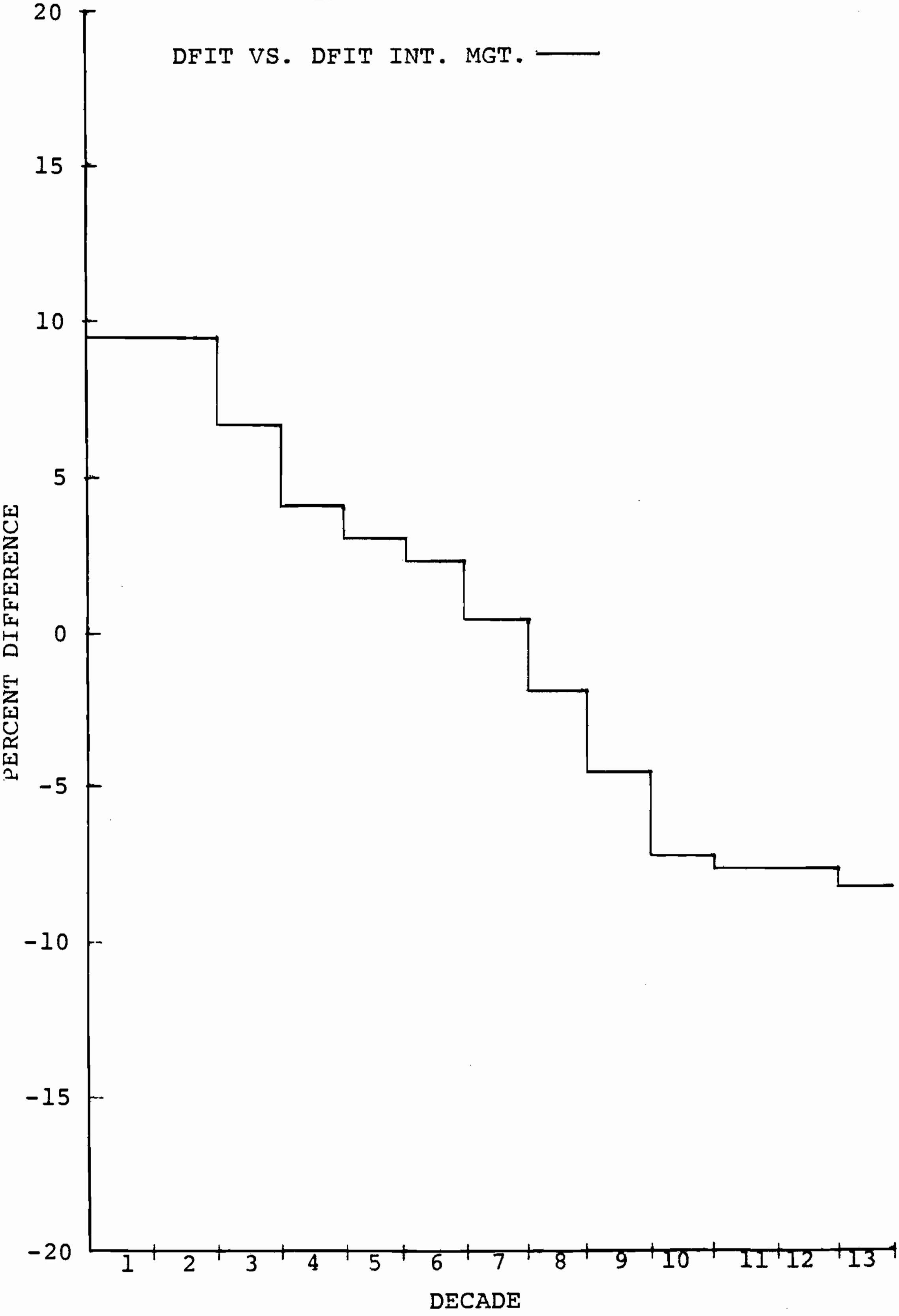

FIGURE A41. HARVEST LEVEL DIFFERENCE

INVENTORY 3

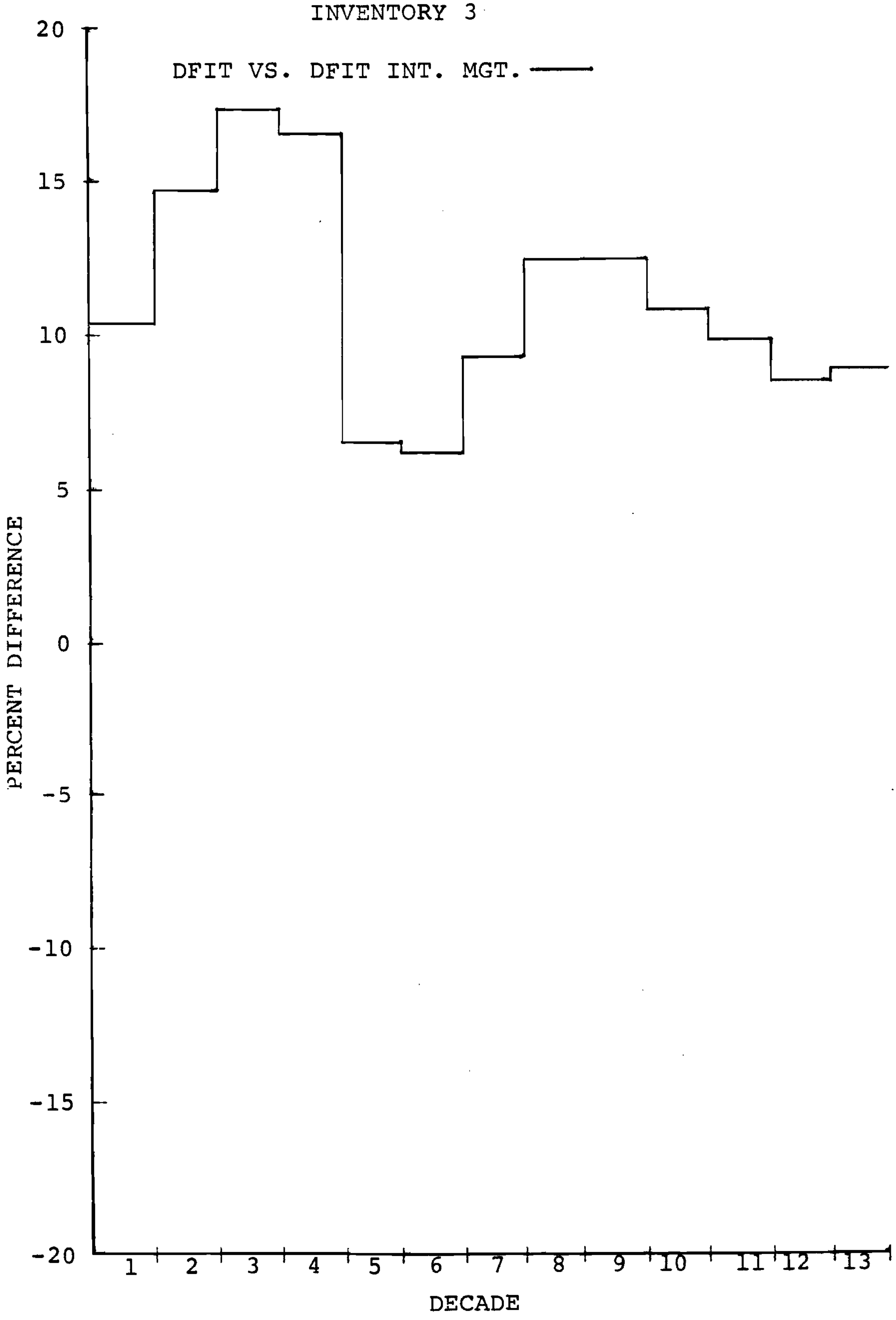

FIGURE A42. HARVEST LEVEL DIFFERENCE
INVENTORY 4

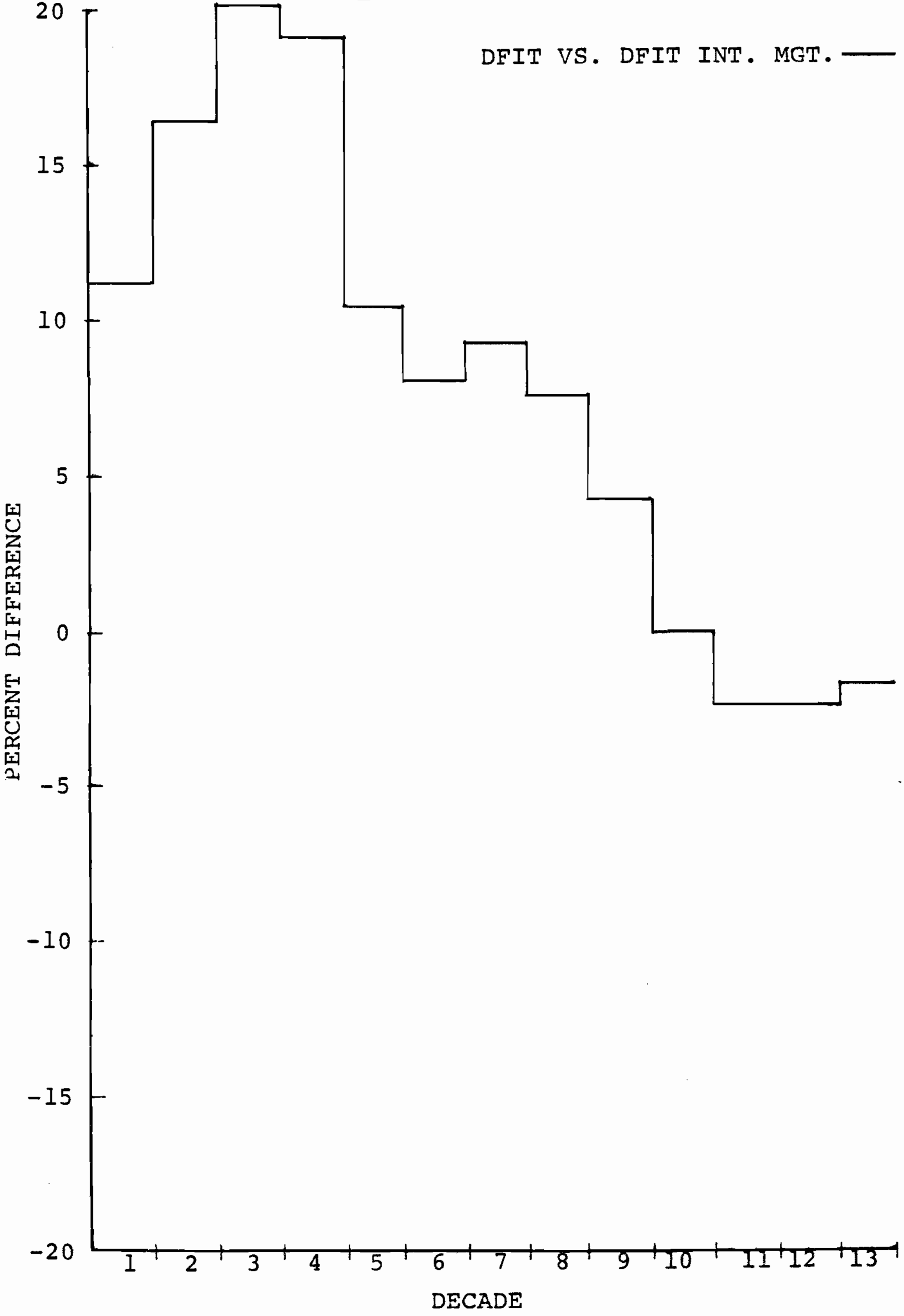

FIGURE A43. HARVEST LEVEL DIFFERENCE
INVENTORY 5

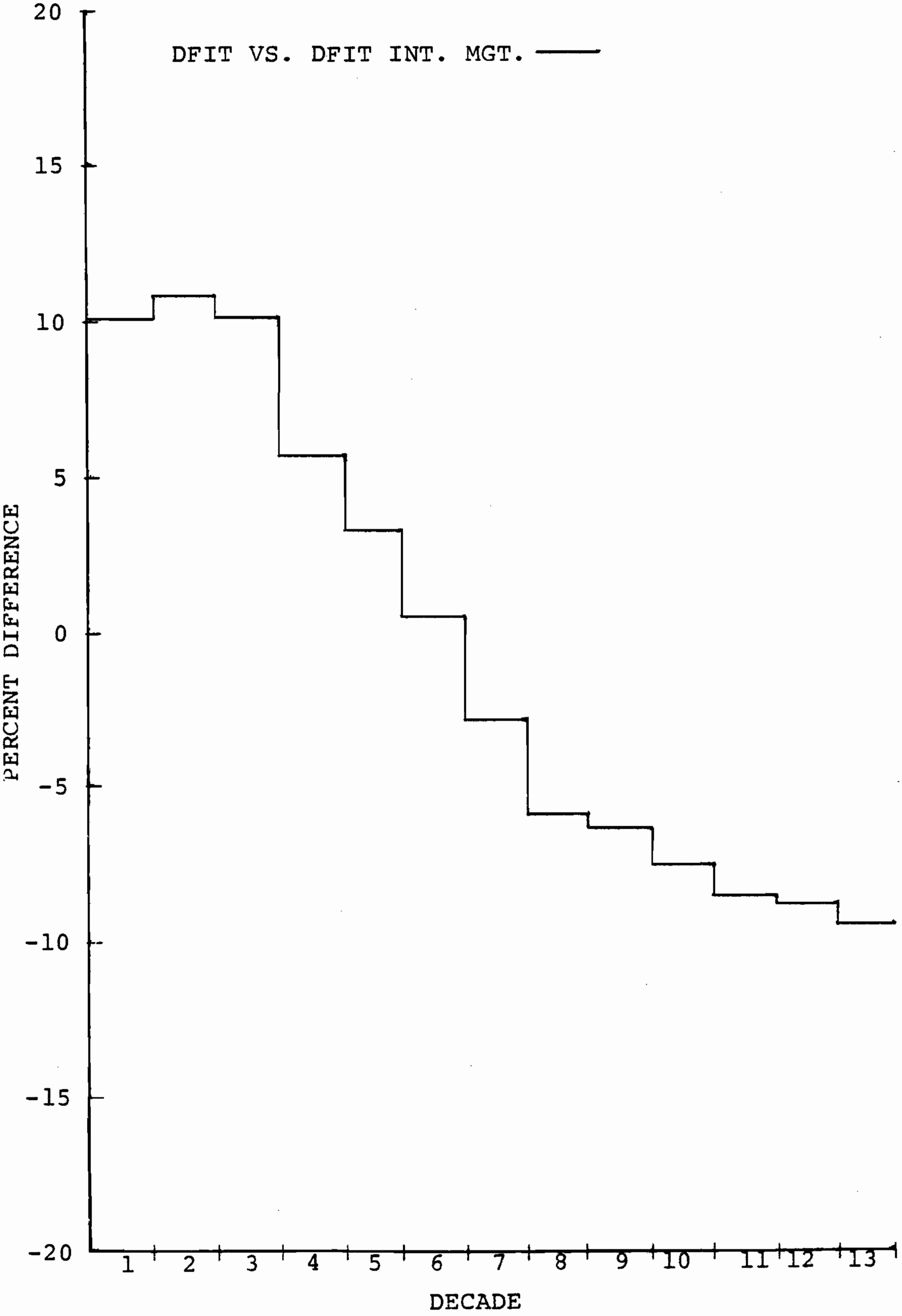

FIGURE A44. HARVEST LEVEL DIFFERENCE
INVENTORY 6

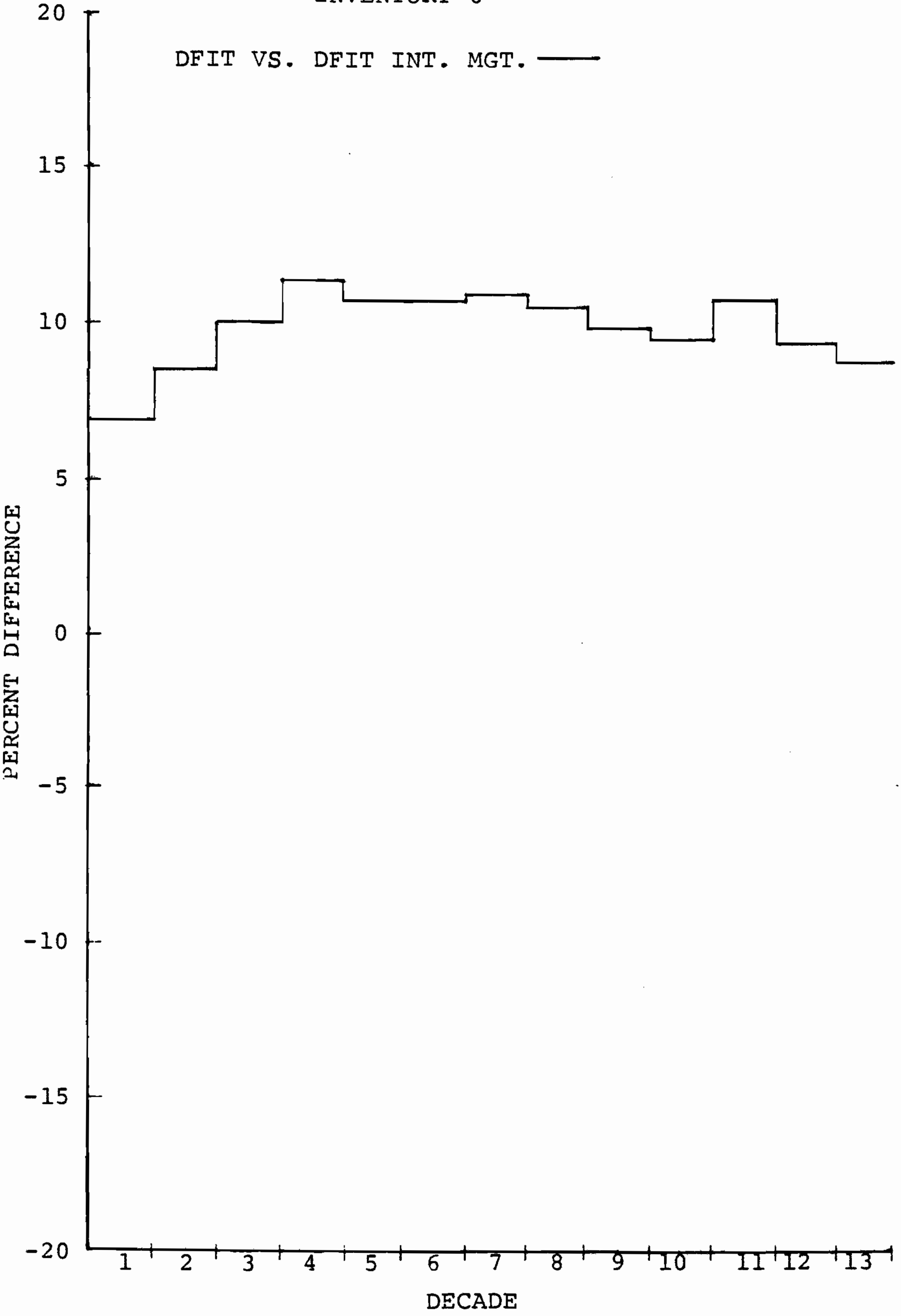

FIGURE A45. HARVEST LEVEL DIFFERENCE
INVENTORY 7

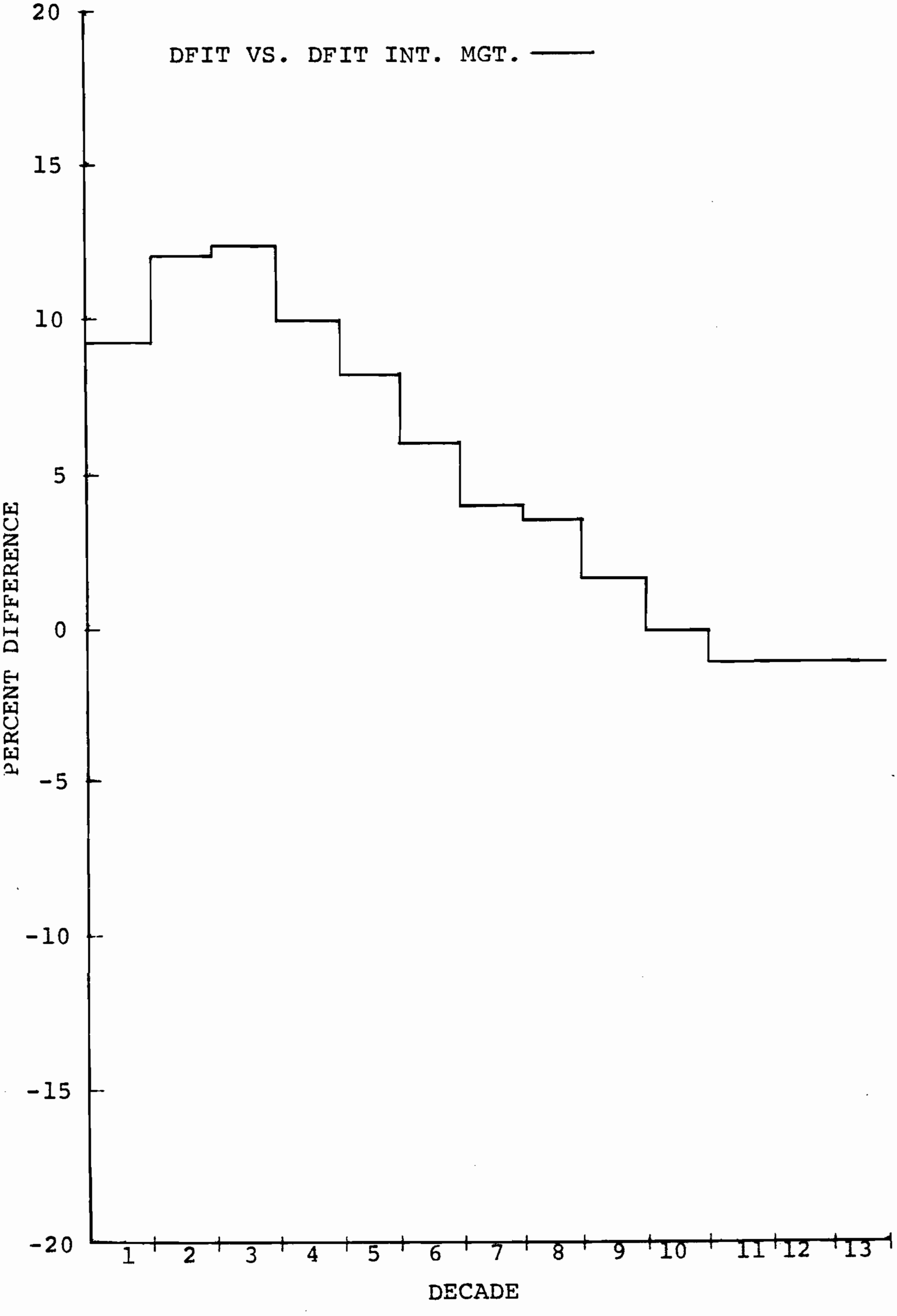

FIGURE A46. HARVEST LEVEL DIFFERENCE
INVENTORY 8