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Major professor

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POST RICE PRODUCTION SYSTEMS ANALYSIS

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ABSTRACT

POST RICE PRODUCTION SYSTEMS ANALYSIS

By

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A systems analysis was made of the in-field post rice production operations in Sri Lanka. Grain losses and technology were investigated and evaluated in relation to climate and labor availability. Field measurement for the two harvesting seasons, the Yala and Maha, were made in selected Sri Lankan farmers' fields. The field measurement data were analyzed and equations were developed for use in formulating a systems model. The model was then used to simulate the response of selected rice varieties to different alternative technological practices.

Grain losses in the harvesting operations were influenced by the timeliness of the operations. Delayed cutting beyond the optimum date (28 to 32 days after 50 percent heading), increased the possibilities of grain loss before and after cutting. Losses due to birds and rodents increased with delayed harvesting. Preharvest shattering losses increased with maturity and delayed harvesting.

Varieties quite resistant to lodging were observed to lodge more when left on the field beyond the maturity period. Lodged plants were then subject to excessive rodent damage. Delays in the harvesting operation were influenced by rain and labor availability.

The attachment of the grain kernels to the panicle began to weaken at maturity and continued beyond. All handling losses increased beyond maturity. Threshing operations utilizing tractors, buffalos, and mechanical threshers caused more transport losses than the pedal thresher. Both premature and delayed harvesting increased the percentage of broken grain at threshing. Cutting at the optimum date of 28 to 32 days after 50 percent heading reduced the percentage of broken grains to a minimum. The pedal threshing system caused the lowest proportion of broken grain for all selected varieties investigated.

The systems analysis of the post production operations identified weaknesses in the various technological packages. The simulation model provided a means studying the influence of climate and labor availability on the post production operations. Variety and post production losses as influenced by labor and weather were simulated.

The pedal thresher was identified as the most appropriate technology for minimizing grain losses. The optimum time for harvesting was between 28 and 32 days after 50

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percent heading. Further research in storing stalk paddy for delayed off-field threshing and a systems analysis of all off-field post production operations is recommended.

Approved Merle L Esmay
Major Professor

Approved D. R. Heldman
Department Chairman

To my late Parents

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CHAPTER I

INTRODUCTION

Problem Overview.

Rice is an important staple in many Asian countries. Increased demand for food and agricultural products, pressed by high population growth, have led many Asian countries to focus national policies toward increased production and self-sufficiency. The drive toward self-sufficiency and increased production in recent years has resulted in the improvement of rice production technologies, which have contributed to higher yields in South and Southeast Asian countries. Higher yielding fertilizer responsive varieties, along with better crop protection, water control and other improved cultural practices, have accounted for the yield increases. Along with the high yields has been an increase in the magnitude of losses throughout the post production handling operations. Due to differing technological practices, these post production losses vary between nations, regions and fields of cultivation. The extensive literature estimate losses from 8 to 30 percent of the total production.[1/]

1/ See works of Ashan and Haque (1975), Efferson (1974), Wimberly (1974) and Bhole (1970).

Improved varieties and production technologies adopted by a majority of Sri Lankan farmers in recent years have, as in other countries, increased rice production. Sri Lankan estimated losses in the post production system are, however, as high as 25 to 30 percent, (Wimberly, 1974). Table 1.1 and Figure 1.1 show estimates of production losses at 20 percent. This projects to a total rice loss for Sri Lanka in 1974 of 313,000 tons in the post production system. If these losses could have been reduced by only one-third, most of the 115,000 tons of imported rice could have been saved, thereby bringing about savings in foreign reserves.

The Mahaveli Ganga Development project envisions intensive production of 360,000 ha of land of which only 53,000 ha are now even single cropped, (Cook, 1976). The introduction of irrigation facilities for existing as well as new agricultural land will make double cropping of rice possible. Double cropping combined with high yielding varieties and improved technological and cultural practices should provide significant increases in rice production. The existing inefficient post production practices can, however, provide a major bottleneck in the increased production plan. It is essential that detailed planning for cropping schedules, production inputs and labor availability also consider harvesting schedules, as well as the availability of drying and storage facilities. The first harvest of 1978 brought about major storage and milling capacity

Table 1.1 Total Production, Total Imports, Losses in Production at 20 percent and Import Requirement from 1970 to 1974.

Year*	Production* (1000 m.t.)	Rice Imports* (Paddy equivalent 1000 m.t.)	Losses at 20%	Import Requirement (1000 m.t.)
1970	1581.1	690.0	316.22	373.78
1971	1365.6	424.0	273.12	150.88
1972	1284.1	428.8	256.82	172.98
1973	1284.1	489.7	256.82	232.86
1974	1567.8	428.3	313.40	114.90

*Source: Department of Census and Statistics, Sri Lanka

problems due to the unforseen rice production increases, brought about by the completion of Stage I of the Mahaveli scheme. The use of temporary storage bins and tarpaulin covers during monsoonal conditions led to a substantial loss of that production. A detailed examination of the post production technological operations was shown to be useful for future increased efficiency.

Appropriate post production methods and technological practices are as important as the rice production phase. The harvesting, handling, threshing, processing, storage and marketing operations determine the quality and quantity of rice that is ultimately available for consumption. Improper post production operations will cause losses in quantity as well as sub-standard rice quality for the consumer. The evaluation of post production losses is

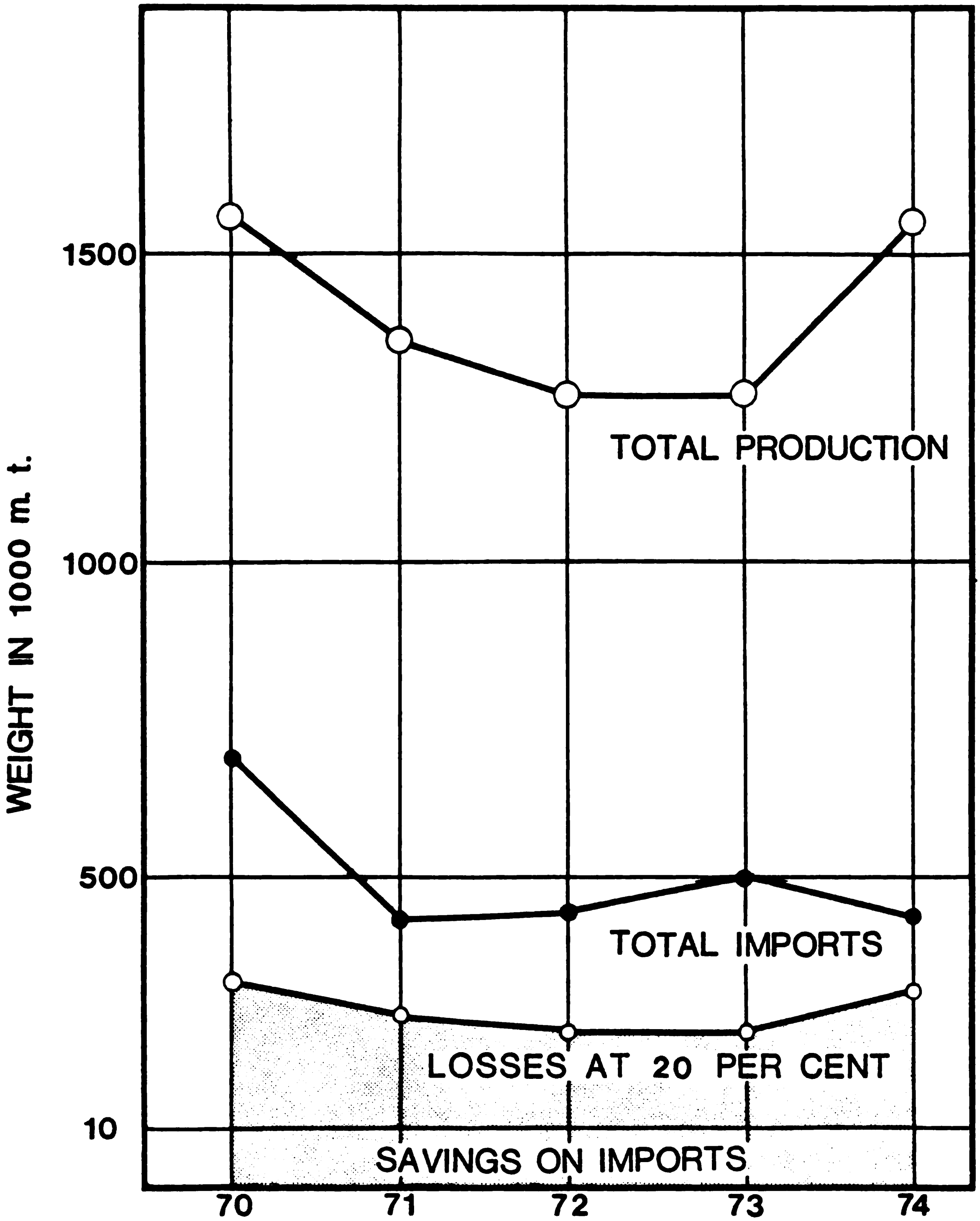

Figure 1.1 Total Production, Total Imports, Losses at 20 Percent, and possible savings on imports from 1970 to 1974.
(Source, Department of Census & Statistics, Sri Lanka)

critical for determining the appropriate technologies for the interdependent post production operations. Independent evaluations of the separate operations in the system have not proven sufficient. Therefore an emphasis must be placed on the study of all post production operations as a system.

This research was designed to formulate a detailed systems analysis of the post rice production operations. The post production system was divided into two subsystems; a) The in-field subsystem and b) the off-field subsystem. Both are shown in Figure 1.2. This study concentrates mainly on the in-field subsystem with special emphasis on the preharvest, harvest, handling, transport and threshing operations.

Objectives:

1) Identify existing technology weaknesses which increase losses both in quantity and quality of available grain.
2) Establish optimum harvesting times for selected varieties to minimize handling and processing losses.
3) Identify the most appropriate alternative technology for minimization of losses.

In order to achieve the mentioned objectives, the following methodology is envisaged.

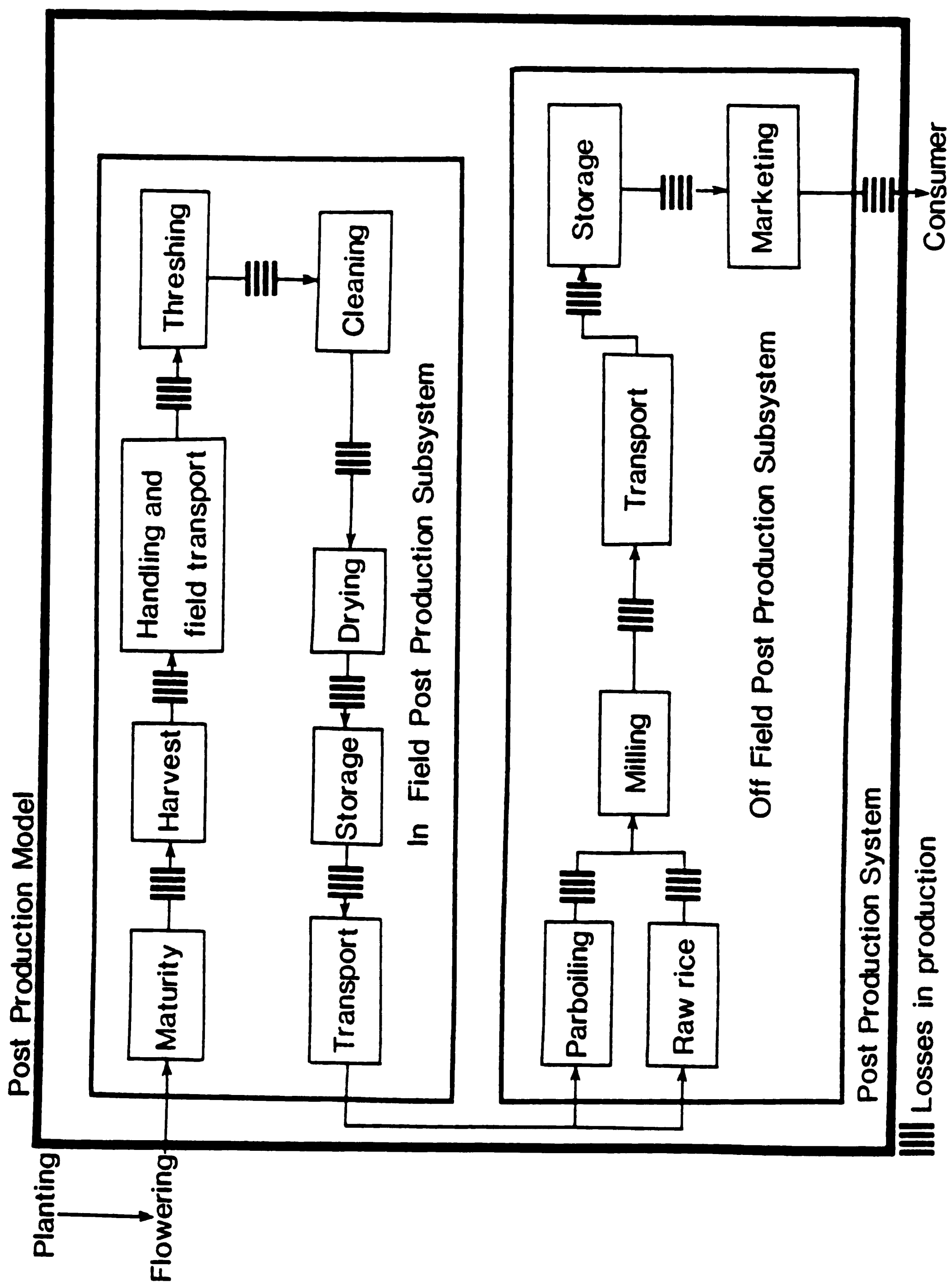

Figure 1.2 The Post Production System

a) Formulate a detailed systems model to analyze the post production process with emphasis on the in-field subsystem.

b) Make field measurements for assessment of losses related to the technological operations.

c) Utilize data from field measurements to construct a systems model to predict the loss response of selected rice varieties to different alternative technological practices.

The results of the study would be used to help disseminate appropriate post production technology information to producers, as well as help formulate the basis for a future systems analysis of the off-field post production subsystems.

Chapter II describes the existing post production operations in Sri Lanka. Chapter III is a literature review of the in-field post production subsystem. Chapter IV describes the methodology and the results in assessing post production field losses. Chapter V describes the in-field post production subsystem model development. Chapter VI describes the results and discussion of the simulation, while Chapters VII and VIII are recommendations and conclusions respectively.

CHAPTER II

EXISTING POST PRODUCTION OPERATIONS IN SRI LANKA

Rice is cultivated in all climatic zones, namely the wet, intermediate and the dry zones. The zone demarkations are governed mainly by climate and geographic features. The dry zone may either be subject to the Northeast monsoon of the Maha season or both the Northeast and Southwest monsoon of the Yala season annually. The wet zone has the benefit of both monsoonal seasons, resulting in a constant annual rainfall. Seasonal fluctuations in weather may determine the outcome of monsoonal patterns in the intermediate zone. The intermediate zone which lies between the wet and dry zone may therefore exhibit characteristics of either zone within a period of one year.

Specific varieties suited for each climatic zone have been developed by plant breeders. Irrigation facilities in some areas have brought about more uniformity in varieties, but as yet a majority of farmers grow varieties best suited to their climatic conditions.

Cultural practices vary between climatic zones because of different sowing and transplanting times used for the numerous varieties. Post production practices in the three zones are basically similar. Few exceptions may be seen in the wet zone where harvesting and stacking is performed early so as to overcome the uncertainties of weather.

Traditional methods are used in all post production operations of rice in Sri Lanka. Use of mechanical or improved technology is limited and mainly applied to the off-field subsystem in post production.

Harvesting

The stalk is commonly harvested in Sri Lanka with a hand sickle. Grist (1975) stated that this method was used in many Asian countries, including India, Burma and Vietnam. Machine harvesting is limited and confined to large commercial farms. Harvesting consists of grasping a number of stalks in one hand and cutting near the base with the sickle held in the other hand. Esmay, Soemangat, Eriyatno and Phillips (1977) reported that the stalks were generally cut from 10 to 15 cm above the ground level and laid on the stubble in small bundles adjacent to the cutting path. Weeraratne, Perera and Yogendran (1977) indicated that these bunches were then left in the field from 8 to 24 hours before collection, Figure 2.1.

Hand sickle harvesting is simple, but labor intensive. The demand for labor during harvesting is the highest among all of the operations for rice production. Amerasinghe (1972), (see Table 2.1) stated that 13.07 man days are required for the second highest labor input, which is the preparation of bunds and cleaning channels. High labor demand during peak harvesting periods could cause labor

Table 2.1. Labour Requirements for Paddy Production in Man Days per Acre in Pre-HYV and Post-HYV Times*

	OPERATION	Family Labour Pre HYV	Family Labour Post HYV	Hired Labour Pre HYV	Hired Labour Post HYV	Exchange Labour Pre HYV	Exchange Labour Post HYV	Total Man Days Pre HYV	Total Man Days Post HYV
Preparatory Tillage	(a) Preparation of bunds & cleaning channels	3.48	3.87	1.51	2.37	1.79	1.83	6.78	8.07
	(b) 1st Ploughing	2.98	3.04	1.60	1.23	1.55	0.72	6.14	5.00
	(c) 2nd Ploughing	2.78	2.27	0.81	0.85	0.75	0.39	4.34	3.51
	(d) Puddling & Levelling	2.60	2.28	0.81	0.91	0.71	0.26	4.12	3.45
	(e) Other	0.31	0.32	---	---	---	---	0.31	0.32
Harvest & Post Harvest Operations	Harvesting and Collection	6.27	7.55	2.96	3.83	2.67	1.69	11.91	13.07
	Preparation of Threshing Floor	0.72	0.81	---	---	---	---	0.82	0.81
	Threshing	3.49	4.32	1.26	1.46	0.98	0.59	5.75	6.36
	Winnowing and Bagging	1.94	2.24	0.68	1.11	0.22	0.12	2.84	3.47
	Transport	0.73	0.92	0.08	0.22	---	---	0.81	1.14
	TOTAL	31.03	39.06	11.05	22.63	9.25	6.75	51.34	68.44

*Calculated for the Maha Season 1970/71.
Source: Amerasinghe (1972)

Figure 2.1. Cutting the Paddy Stalk

Figure 2.2. Windrowing of Cut Stalk

shortages that would increase delayed harvest and pre and post harvest losses through exposing the paddy to unfavorable weather conditions.

The labor distribution throughout rice production varies with the region and land ownership. Small land owners may use family labor and/or exchange labor. The use of high yielding varieties have brought about some change in labor employment practices. Amerasinghe (1972) reported that more family and hired labor and less exchange labor were now employed whereas large land owners used hired or contract labor entirely.

Proper water management is important during the harvesting operation. Fields should be drained 7 to 10 days before the expected harvest date. This is when the uppermost kernels on most tillers are in the hard dough stage and turning from green to yellow. VoTong and Ross (1964) reported that field drainage hastened maturity and improved harvesting conditions. Effective water management is generally possible under irrigated conditions, but under rainfed cultivation uncertain weather may cause difficulties.

Bundling

The cut bunches of stalk paddy are commonly left to dry in the field overnight. Experienced harvesters windrow the bunches for easier collection, Figure 2.2.

Some 15 to 20 small hand bunches of cut stalk paddy are normally tied with one twine. The stalks are grouped into a buncle in such a way that the panicles remain in the center, while the cut ends of the stalk face outwards. This prevents excessive grain loss during transport. Bundling varies according to the type of labor used. Bundles may be made smaller for women and children. In a few areas a mat may be tied around the bundle to collect falling grain during transport. This practice is limited mainly to very small holdings. The bundles are transported immediately to the threshing floor, Figures 2.3 and 2.4.

Transport

Threshing floor ownership may vary according to the size and location of the farm. Farmers may have a common threshing floor or may possess their own. Bundles are normally head carried, Figure 2.5. The distance varies from field to field depending on the threshing floor location. A tarpaulin sheet may be used in larger fields to construct various temporary threshing floors. The transporting distance is then reduced.

Farmers not possessing their own threshing floor may have to transport the bundles a considerable distance. Bullock carts can be used to transport bundles. A tractor and trailer may also be used if available, Figure 2.6. Head carrying is then eliminated. Cart linings to prevent the

Figure 2.3. Forming Bundles of Cut Stalk for Transportation

Figure 2.4. Transporting the Cut Stalk

Figure 2.5. Method of Carrying the Bundle on the Head

Figure 2.6. Use of Tractor and Trailer for Transport

loss of grain have been observed in certain cases, but they are not a common practice. The bundles may be temporarily stacked on the field bunds during unfavorable rainy conditions when transport is hindered.

Threshing

The transported bundles are normally stacked on the threshing floor. During bad weather farmers may make large stacks about 10 feet in height and 5 feet in diameter. Stack size varies with the experience of the people constructing them, Figure 2.7. Stacks are made as water tight as possible to preserve the panicles for periods of up to two years.[2/] The moisture condition of the stalk and grain at stacking time determines the storability of the paddy. The stack function is two-fold: 1) for storage of the stalk until favorable weather arrives, and 2) for holding until threshing can be done. Availability of labor, animals, machines or tractors for threshing as well as social obligations affects the time of threshing. Stacks provide more flexibility for the farmers to thresh at their own convenience.

Threshing floor availability depends on the farm size and the economic condition of the farmer. Small farmers may just place a jute or tarpaulin sheet over hard ground

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[2/] This was found to be the experience of many farmers who adopt the practice of stacking.

to serve as a threshing floor. In some cases threshing may be done directly on the rough, hard ground. Mud or cement plastered threshing floors are better, but more expensive and are generally owned by farmers having a higher economic status.

Five methods of threshing are used in Sri Lanka.

a) Manual treading

b) Animal treading

c) Tractor threshing

d) Pedal threshing

e) Mechanical threshing

Manual treading is practiced in a limited way in areas of the wet zone where farm sizes are extremely small. This method involves spreading the stalk paddy on a hard surface and then walking and trampling on them until the kernels are detached.

For animal treading, Figure 2.8, the stalks are laid two or three sheaves deep in a circular pattern on a threshing floor. Paired buffalos are then driven slowly around to trample out the grain. This is probably the most traditional practice in Sri Lanka, and used in the dry, intermediate and wet zones. Many farmers who do not own buffalos rent them. The usual payment is a bushel of paddy rice per pair of buffalos per day.

Four wheeled tractor threshing is used some. It is more costly than the use of buffalos, but is more

Figure 2.7. Stacks of Cut Stalk After Transportation

Figure 2.8. Threshing by Means of Buffalos

convenient and increases the threshing rate. The tractor is run continuously in a circular path over stalk paddy laid on a threshing floor, Figure 2.9

Mechanical threshing is rare and restricted to large farms and research stations. The pedal thresher though not commonly used at present is manufactured locally and may have a potential for the future, particularly for small farmers in the wet zone.

Winnowing

Rough rice is winnowed traditionally with a flat round tray of rotan, edged with an inch high lip.[3/] The paddy is tossed and shaken with a twist of the wrist to move the empty husks, light kernels and chaff to the edge of the tray opposite the worker. The chaff and empties are thrown over the edge of the tray. The tray is then held above the head and shaken gently while the grain falls to the ground. The remaining chaff and dust is carried away by the wind. The traditional method is simple, but needs considerable experience to performn

Mechanical fans are being introduced. A bicycle peddling mechanism with a fan attached in place of the wheel has been used. The pedals are turned by hand. This is a simple technique manufactured by local blacksmiths. Fans are also attached to the PTO of two-wheeled and 4-wheeled

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[3/] Rough rice is defined as unhusked rice.

Figure 2.9. Tractor Threshing

tractors. Cleaning is fast and efficient, but is not an energy efficient operation. This method is, however, used on the larger holdings of paddy land, especially in the dry zone.

Drying

A majority of farmers dry their crops on the field before harvest. If the weather is favorable the crops are left in the field until uniform drying is achieved. Ohja (1974) reported that field drying, however, was very slow and often took about two to three weeks after maturity. Often the crop is left until the grain and stalk turns golden yellow, with a moisture content of about 15 percent. Field drying exposes the grain to alternate drying and wetting cycles during rainy weather and during day or night temperature and humidity variations. Farmers normally prolong harvesting until all panicle kernels have attained maturity. Delayed harvest and field drying aids grain removal with traditional threshing methods, but also increases losses.

After harvest the cut stalk paddy is left on the field or bunds for further drying, usually for a period of 8 to 24 hours. Some farmers may harvest at a higher moisture content and allow the stalk paddy to lie on the stubble longer. In either case the grain is exposed to wet weather and cycling moisture conditions.

The threshed grain is dried on various types of sun drying floors as is done in many Asian countries. Mats, cemented floors, roadways and household yards are some of the common places for sun drying. The kernels are spread evenly about 5 to 8 cm in thickness, on the drying yard and intermittently stirred by human labor until the grain is dried. At night or when rain or heavy dew occurs, the grain paddy is heaped and covered, then spread out again when conditions are favorable.

Storage

The farmers are usually in need of money so dispose of their crops at the earliest opportunity. Farmers store sufficient quantities of paddy to provide food from one season to another as well as provide seed for the next cultivation. Weeraratne, et al. (1977) indicated that about 30 to 50 percent of the total production was retained. Farm storage is therefore restricted to small storage structures often constructed adjacent to the farm house. Storage structures are oval in shape with a wide circular opening at the top. They are made of split bamboo sticks, plastered with clay and lime and supported by wood or stone pillars. Bag and bulk storage of paddy in small quantities may be practiced in farm households, but is temporary prior to disposal at the market.

Village level storage structures, often at Paddy

Marketing Board (PMB) purchasing points, are larger and located centrally to best serve all farmers in the area. As bagged storage capacity is small, the paddy is transported to the regional PMB warehouse at the earliest convenience. At present PMB storage capacity is not adequate. The Paddy Marketing Board has about 275 warehouses with a capacity of about 350,000 tons. Most of the storages have roofs made of corrugated asbestos or galvanized iron sheets. A few have brick walls, while the others have walls made of galvanized iron or asbestos sheets, or a combination of brick walls and sheets. Most storage is in bags and due to poor structures the grain is exposed to damage by moisture, rodents, insects and birds. During peak harvests such as the Maha harvest of March to April, 1978, temporary tarpaulin covers and imported prefabricated silos were used to provide bare minimum storage. PMB storage is confined to large godowns or warehouses providing flat or sack storage. Bulk storage is limited, but could be a possibility in the future.

Rough Rice/Milled Rice Movement and Trading Practices

a) Historical Preview.

Prior to World War II rice trading was in the hands of the private sector. Imported rice to meet the needs of the country was very cheap. Domestic production was below 25 percent of the country's total requirement. Rice shortages for the consumers of Sri Lanka were envisioned by 1942. The World War II disruption of shipping and allied services from the principal exporting countries of Thailand and Burma created further rice shortages. A rice rationing scheme was then introduced. Simultaneously, an Internal Purchasing Scheme (IPS) was launched by the government to maximize local paddy rice production.

The IPS which began as a strict government authority during a war emergency was not discontinued. The post war functions of the scheme were subsequently transferred to the Department of Agricultural Marketing, which discontinued the requisition of paddy rice from the farmers and instead incorporated a price support scheme. The farmers were assured a floor price if the paddy rice was sold to the government. Rice mills and storages were imported and constructed by the government in the early fifties to process the purchased paddy rice.

The marketing department transferred its rice handling responsibilities to the Department of Agrarian Services in the mid nineteen fifties, and confined its activities to the purchase of perishable farm products, such as vegetables and fruits. The transfer of responsibilities brought the mills, stores and other facilities under the authority of the Agrarian Services. The price support scheme was continued and in 1961 a guaranteed price was legalized by an Act of Parliament.

The government concentrated on making the country self-sufficient in rice in the post Independence period from 1948. The provision of irrigation facilities increased the area of cultivated land and intensified research activities were carried out to breed highly productive rice varieties. These efforts brought about the impact of high yielding varieties beginning in 1966. The Agrarian Services Department then found its resources for collecting, storing and milling heavily strained. The arrangements until then were made by the government to organize purchases through its agents, viz. the cooperative societies, to store and mill purchased rice. The milled rice was then supplied to the Food Commissioner who in turn distributed it through a ration program to the people of the country.

The recognized need to maximize production resulted in the supply of agricultural credit, fertilizer subsidy, improved varieties and technical knowhow to the farmers through the Agrarian Services Department. Its activities were further expanded through the implementation of the Paddy Lands Act, for the supply and distribution of fertilizer and the purchase of a variety of other grains such as pulses and commercial crops. The magnitude of these operations led the government in 1970 to recognize the need for a separate agency to take complete responsibility for paddy rice purchase, storage and processing throughout the nation. The Paddy Marketing Board created in 1979 was made responsible for the post harvest movement of rough and milled rice throughout the country.

b) The Paddy Marketing Board -- Its Objectives.

A new act of Parliament in March 1971 established the state sponsored corporation to handle the purchase, storage and processing of paddy rice. The RPDC Training Manual (1977) stated the PMB objectives as follows:

i) Carry out the business of purchasing, hulling, milling, processing, supplying and distribution of rough and milled rice.

ii) Carry out any other business incidental or conducive to the attainment of the first objective.

iii) Perform duties which, in the opinion of the board are necessary to facilitate the proper carrying out of the business.

The Act, for the purpose of purchasing paddy by PMB, authorized purchases by Institutions ranging from cooperative societies to individuals. The scope of the PMB activities covered all 22 districts in the country. Paddy purchasing authority was given to 368 Multi-Purpose Cooperative Unions and Agricultural Productive Committees (APCS) with 4,000 purchasing centers throughout the country. Wimberly (1975) reported that the PMB, following the purchase of rough rice, was responsible for the transport, storage through its 275 locations, and processing by the

20 PMB mills and 500 authorized commercial mills.

c) Purchasing of Rough Rice.

The PMB changed the purchase of rough rice from volume to weight basis in 1972. The change was phased in for three years and completed in 1975. Pereira and Samuel (1976) reported that finances for purchasing rough rice was supplied to purchasing cooperatives as a loan by the state banks. The rough rice was purchased by the following PMB enforced standards:

i) Impurities must not be greater than 1% by weight.

ii) Chaff content must be less then 9% by volume.

iii) Rough rice must be well dried. 15% on a wet basis is considered dry, but 14% is preferred.

iv) Rough rice must be free from insect and fungal damage.

Purchasing agents are paid a commission for handling and transport costs. Rough rice is transported to the PMB stores by truck and tractor trailers in jute sacks. Rough rice is again inspected, tested, graded and packed into either 110 or 140 lb net weight bags, then stored in the PMB storage facilities.

Private traders may purchase 20 to 30 percent of the farmer's production in addition to the PMB purchases. The private trader purchase price is generally lower than the guaranteed PMB price. Farmers are compelled to sell to private traders because they may have to repay loans taken for cultivation or goods bought from the trader. Also it is easier to obtain "cash in hand" from private traders compared to the bureaucratic red tape of PMB. Storage, handling and processing facilities of the private traders, however, are generally poor and result in a low quality product at the market.

Rough rice may also be purchased by the Department of Agriculture for seed. These purchases are restricted to certified seed farms that belong to the larger and more progressive farmers. The seed is stored in the Department seed stores located in the 22 districts. It is then distributed through the extension offices which cater to the farmers needs. Seed purchases and handling are less, thus losses are lower in comparison to the rough rice bought for the retail market. A higher price is paid for seed than that for market rough rice. The higher price provides an incentive for the production of better quality seed.

d) Rough Rice Milling.

Rice may reach the consumer through the ration program, the open market or the PMB retail outlets. Rationed rice is generally not polished to any specification, since 85 percent of the PMB purchased rough rice is milled by private registered millers. The private millers in Sri Lanka have not invested in modern rice milling machinery and continue to operate the steel huller types. Practically all the rice issued through rationing is repolished in private mills. Studies by the Rice Processing Development Center in Sri Lanka revealed that 96 percent of the households (laborers, merchants, pensioners) regardless of affluence reprocessed their rationed rice at a miller or by home pounding.

Consumer preference for rice varies by district throughout Sri Lanka. Small rounded grains, commonly referred to as "samba", have a better market value than other varieties. The newly introduced "basmathi" rice from Pakistan brings a premium of the market. A majority of all consumers prefer parboiled rice although those in the southern section of the country have a distinct preference for raw rice. Some consumers prefer brown grained rice instead of the common white rice. The varied consumer preference makes it more difficult for the PMB to satisfy the demands placed on the rationed rice. The PMB purchased a mixed variety of rough rice from farmers who prefer to cultivate different high yielding varieties. The mixed consumer preferences as well as mixed cultivation practices placed a heavy strain on the existing milling capacity.

Weeraratne, et al. (1977) reported that in 1978 there were about 1,826 mills in operation, divided into the following categories:

i) 20 owned by the PMB.

ii) 18 owned by cooperative societies.

iii) 847 owned by private quota millers (quotas regulated by the PMB).

iv) 941 owned by private individuals for customer milling and polishing.

The distribution and types of rice mills operated above are presented in Table 2.2.

e) Milling of Raw Rice.

The Agrarian Services Department issued raw rough rice milling quotas to steel huller mills. The head rice recovery, however, was low. The PMB, as a policy decision, did issue rough rice for raw milling to mills using steel hullers. A 6 to 7 percent increase in rice and a 12 to 16 percent head rice recovery was obtained by mills using rubber roll shellers. The policy decision in turn encouraged the private millers to modernize their existing mills.

Prior to 1970, pre-cleaning facilities were limited to a few mills where cleaning was done with either manual or mechanically oscillating, single, inclined seives. Raw rice was polished mainly by steel hullers and occasionally with a horizontal abrasive stone polisher. The stone polisher achieved a 3 to 5 percent degree of polish for a single pass. A further decision taken by the PMB insisted that all mills operating quotas for raw milling should possess rough

Table 2.2. The Distribution and Types of Rice Mills in Sri Lanka up to 1978

Mills owned by	Rubber roll sheller	Under runner disc sheller	Steel huller	Raw Milling	Par boiled milling	Total
Paddy marketing Board	8	2	10	10	10	20
Cooperative quota mills	12	-	6	12	6	18
Private quota mills	432	3	412	435	412	847
Private customer mills	-	-	941	941		941
Total	452	5	1,369	457 (941)	428	1,826

The 941 mills of the private sector, available for customer milling was not classified as raw and par boiled as both are practiced in these mills.

Source: Weeraratne, Pereira and Yogendran (1977).

rice pre-cleaners and vertical cone polishers. Rough rice cleaners reduced the presence of sand, stone and other impurities, while the vertical cone polisher increased head rice recovery by 10 to 12 percent over the steel huller.

f) Parboiled Milling.

1. Parboiling.

Many methods are used in the parboiling of rice. Farmers used small earthenware pots to parboil their domestic needs of rice. This is a very common practice and could be seen in many small village homes. In large scale processing mills parboiling methods varied, but three methods common to many were:

i) The cold soaking process.

ii) The "goviya" process.

iii) The hot soaking process.

The rough rice in the cold soaking process is soaked in cold water for a period of 36 to 48 hours, depending on variety, and steamed for 30 minutes thereafter. The soaking tanks are normally made of cement or concrete and have a capacity of 3 to 4-1/2 tons. The steaming tanks are of mild steel with perforated bottoms to facilitate steaming. The steel tank has a capacity of 1 to 1-1/2 tons, depending on its dimensions.

A rough rice and water mixture is heated in a chamber from 70^{o} to 80^{o}C in the "goviya" process, Figure 2.10. The

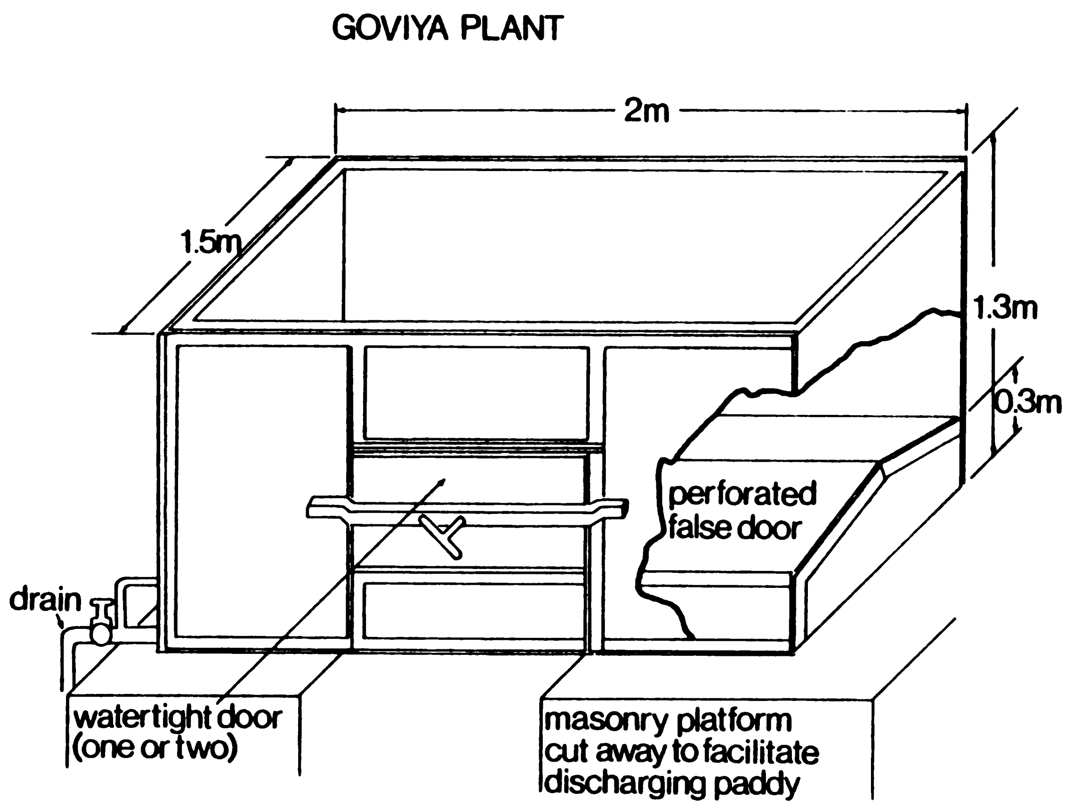


Figure 2.10 Diagram Illustrating the Goviya Plant (Source: Weeraratne, et al.)

mixture is soaked for 4 to 5 hours after which the hot water is drained off to the false bottom serving as a steaming level. The soaked paddy is then steamed for 15 to 30 minutes by heating the water below the perforated sheet. The plant is a rectangular steel tank of 2m x 1.5m x 1.3m, mounted on a fireplace adjacent to the drying floor. The capacity of this tank is 1-1/2 tons.

The water is heated up to 80°C in the hot soaking process and the rough rice is stirred into it. The resulting temperature drop to about 70°C is maintained from three to four hours until the rough rice is soaked. The hot water is drained off and the rough rice steamed for a further 15 to 30 minutes.

Mechanical drying is limited and practiced with obsolete machinery. Parboiled rough rice is sun dried. The rough rice is spread over a drying floor and allowed to dry under the sun for about three hours. At regular intervals the rough rice is stirred by manual labor so that grains dry uniformly. The rough rice is collected and allowed to temper, either heaped and covered in the sun or heaped in the shade. After two hours of tempering, the rough rice is spread on the floor to dry for three hours. The sun dried, parboiled rough rice is then milled.

2. Milling of Parboiled Rough Rice.

Steel hullers are widely used for milling parboiled rough rice. They are easy to operate and have a low initial and maintenance cost. Parboiled rough rice is milled in a batch of two or three steel hullers, hulling and polishing the grain at the same time. In some mills the parboiled rough rice is passed through rubber roll shellers where 40 to 60 percent of the shells are removed. The remaining shells are removed and the grain is polished when rice is passed through a steel huller for the second time.

g) Trading Practices.

The major portion of rice processed by and for the PMB is bought by the Food Commissioner for issue on the ration, while the rest is sold at off-ration PMB sales centers. The Food Commissioner in turn issues rice to cooperative stores and their authorized agents who distribute the rice on the ration, Figure 2.11. Deficiencies of rice for distribution on the ration is supplemented with imported rice. In 1974 the government imported 428,300 tons of rice (rough rice equivalent) to be issued on the ration, Table 1.1.

Difficulties associated with low milling capacity was experienced with the Maha harvest of 1977-78. The increased rough rice production and low milling capacity led the government to offer the consumers an option of either taking milled rice or a rough rice equivalent on the ration. Many

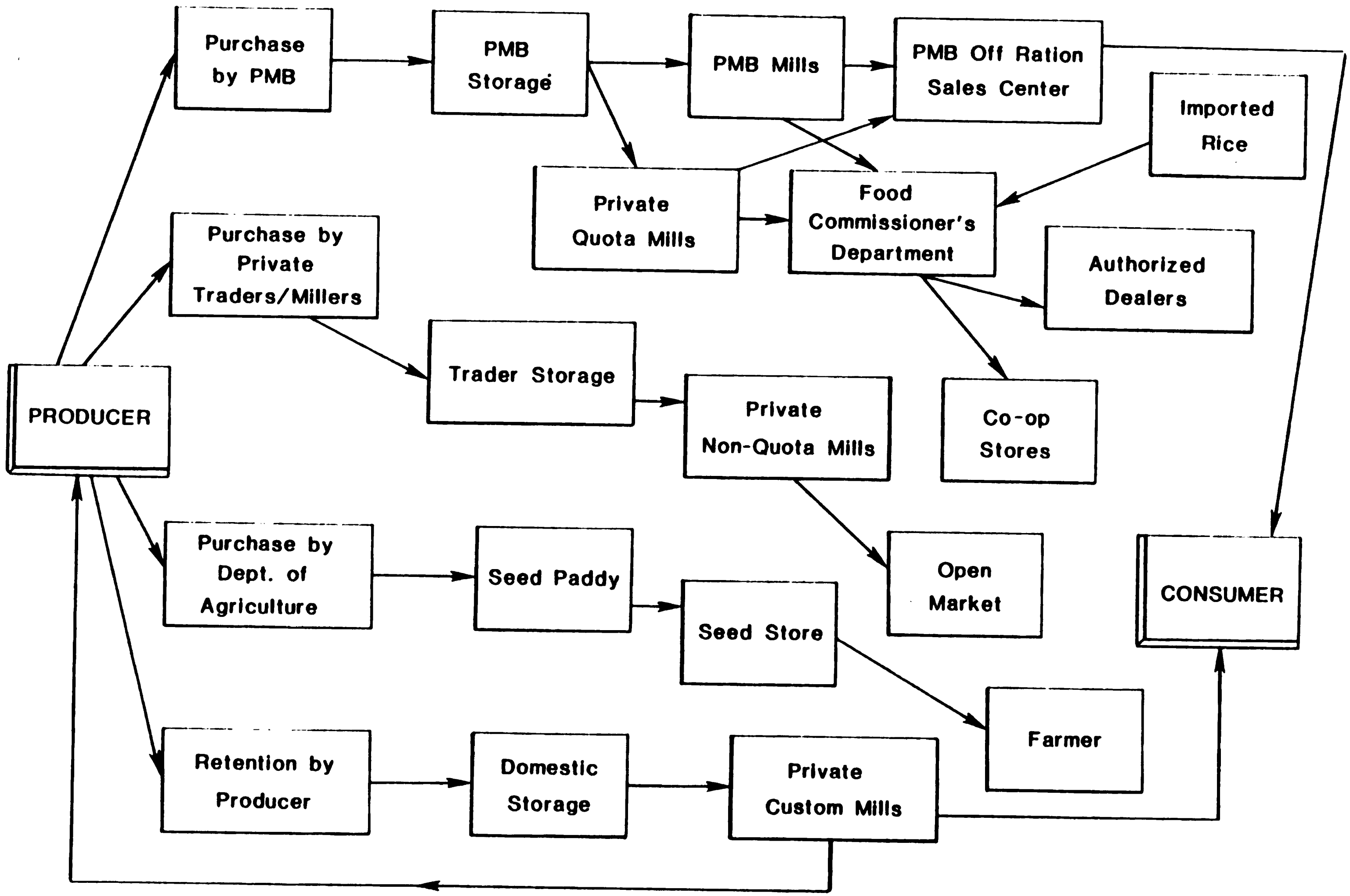


Figure 2.11 Schematic Diagram of the Rough/Milled Rice Post Harvest Movement in Sri Lanka

consumers preferred the latter because they could process the rough rice at home to their satisfaction rather than receive sub-standard milled rice on the ration. A small quantity of milled rice is distributed on the off-ration market to tourist establishments, government canteens and similar institutions.

Rough rice processed by private non-quota mills is sold as rice in the open market. The rough rice retained and processed by farmers is either used as rice for their consumption or sold to the consumer through open markets. Farmers who exhaust their own stocks before the next harvest are forced to purchase their rice from open markets.

The post production processes in Sri Lanka are complex. The movement of rough rice/milled rice from harvest to the consumer involves varying handling and processing operations. The efficiency in managing these operations determine the quality of the final grain product reaching the consumer. The factors influencing the efficiency of the total post production system are numerous and discussed in the next chapter.

CHAPTER III

LITERATURE REVIEW OF THE IN-FIELD POST PRODUCTION SYSTEM

A major factor contributing to the economic nonviability of farmers and farming areas in developing countries is their inability to handle and store products efficiently. Living standards of rural communities depend not only on the range and quantities of the food grown, but also on the facilities for efficient handling, drying, storage and marketing of those products. An increase in rice production resulting from the use of improved technology and high yielding varieties has been observed, yet traditional post production practices limit the maximum production capacity of the farming areas. Maranan and Duff (1978) reported that while much effort had been made to minimize post production losses in processing and marketing of rice, understanding the effects of post production technologies influencing losses in rice quality and quantity on the farm level system was as important. Factors contributing to losses on the field and off the field are numerous and vary with economical, technical and environmental conditions. The complex interdependencies influencing the final quality and quantity of grain in the in-field post production subsystem are described in Chapter III.

The production practices of the farm level subsystem begins at land preparation and terminates at either farm storage or the market sales point. The technology adopted by the farmers, their families and hired labor are traditional and subject to grain losses. The magnitude of losses varies within farms and farming areas, depending on the experience and handling techniques of the farmers. In Sri Lanka, similar post production operations are practiced throughout the country and are therefore subject to similar influences affecting grain loss. Post production operations on the farm level subsystem with possible alternative techniques are illustrated in Figure 3.1.

3.1. Field Losses Before Cutting -- Preharvest Losses.

Field losses from flowering to harvesting are included in the preharvest operations. Losses may result from shattering, lodging, insects, rodents, birds and disease. Although insects and disease play an important role in determining the final production output, this study, while recognizing their impact, on the final system will not delve into a discussion. However, the influence of bird and rodent damage is important and will be discussed.

a) Shattering Losses.

Premature shedding or separation of the grain from the panicle is known as shattering. During natural shattering or threshing the spikelet is separated from the junction of the lower sterile lemma and the rudimentary glumes, Figure

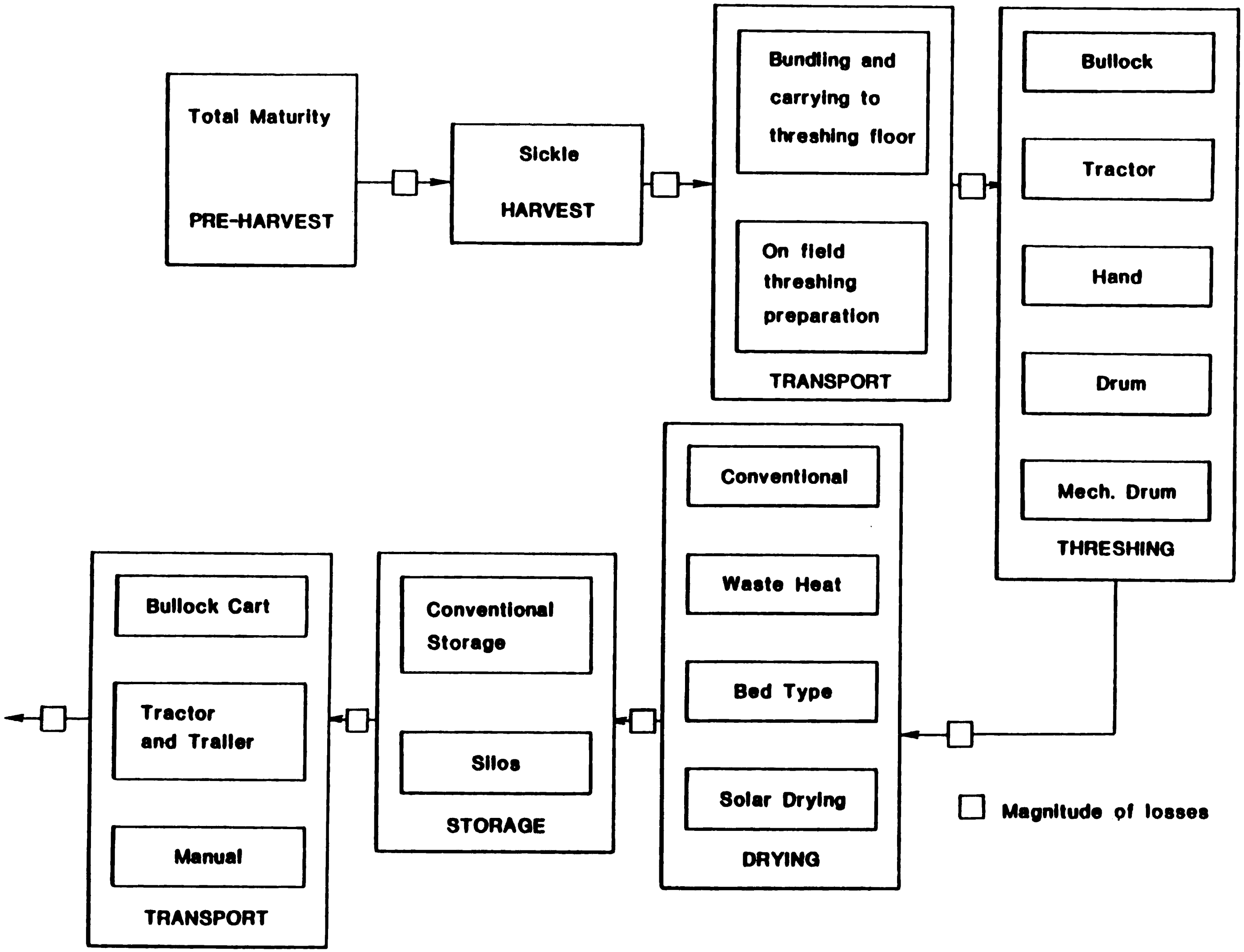


FIGURE 3.1 The In-Field Post Production Subsystem

3.2. Te-Tzy and Bardenas (1965) indicated that the relative degree of development between the sterile lemmas and the glumes was associated with the ease in shedding and shattering. However, in certain varieties shedding may occur by the fracture of the pedicel or by the disarticulation at the joint of the pedicel and rachilla. Grist (1975) indicated that if the joint of the pedicel and the rachilla was a deep ball and socket form, there was less tendency for shattering to occur.

Jacobi (1974) reported that shattering of grain was basically genetical. Differences in characteristics were seen between rice varieties and were correlated with the degree of development of the abscission layer between the spikelet and the glumes of the pedicel. Improved hybrid varieties were seen to shatter more easily than traditional varieties. The ease of shattering was a trait introduced by breeders to facilitate a higher threshing efficiency.

Shattering losses are influenced by the variety, maturity and handling operations. Esmay, et al. (1977) reported that varietal characteristics such as plant height, number of tillers per plant, plant density and number of grains per panicle influenced shattering. Heavier grains tended to shatter more easily due to the weight of the grain acting on the abscission layers.

Dungan and Ross (1957) reported that maturity was reached in most grain crops when the endosperm was in the stiff or hard dough stage. For most varieties, full maturity was reached between 25 to 35 or 40 days after flowering, although varieties differed in the duration from anthesis to maturity. Hoshikawa (1972) observed that grain development was essentially complete within three to four weeks after flowering. Associated with maturity and degree of ripeness was the decrease in moisture content of the grain and the plant, Figure 3.3. Esmay, et al. (1977) observed that the moisture content of the grain initially decreased faster than that of the plant, although the plant had attained physiological maturity. Battacharyya and Chatterjee (1977) indicated that the rate of decrease in moisture content was high at the early stages of grain development, but receded towards maturity. However, weather conditions and high soil moisture content retarded the onset of maturity and the subsequent decrease in grain moisture. Wanders (1974) stated that in climatic conditions with high sunshine, low hygrometer and dry winds, maturation was faster and grain moisture decreased from 23 to 16 percent in four days. The decrease in moisture content of the stem, resulting from slower water uptake during maturity, makes the stem and allied plant tissue brittle, simultaneously weakening the attachment at the junction of the lemma and glumes. The weak attachment is susceptible to wind and rain, increasing the potential for losses as grain begins to dry beyond maturity.

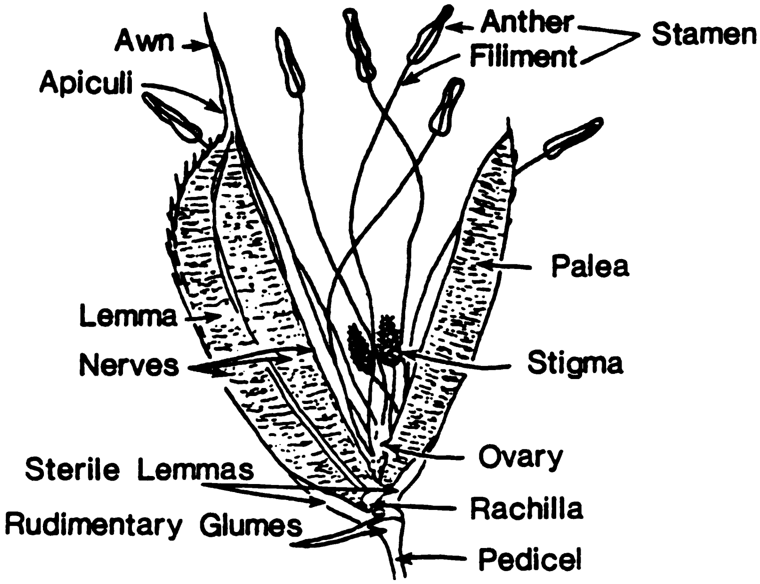


Figure 3.2 Parts of a Spikelet (IRRI, 1965)

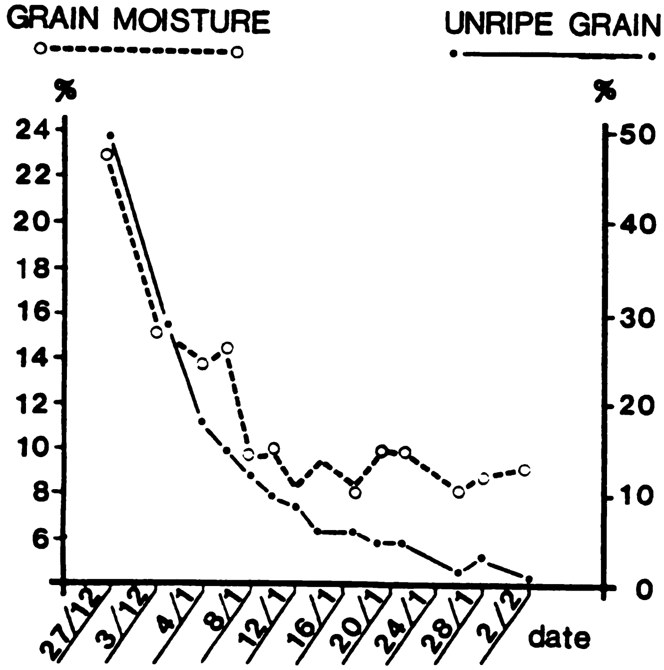


Figure 3.3 Decrease in moisture content of the grain after maturity (From Wanders 1974)

Te-Tzu and Bardenas (1965) reported that characteristics such as grain shedding, grain weight, grain dormancy, etc. have a marked variability when grown under different environments. Battacharyya and Chatterjee (1977) observed that grain ripening in the cool season (July to December) were heavier than those that matured in the summer. Ramaiah and Rao (1953) reported that when varieties prone to shattering were grown off the appropriate season, they tended to shatter more. Some varieties shattered more when harvested in summer while others shattered more in autumn and at higher altitudes. Bhalerano (1930) reported that farmers were said to believe in soil condition, quantity of humus, water stagnation at harvest and rapid drying after maturity, as some environmental factors contributing to shattering. Again the influence of climatic factors such as wind and rain provide environmental stresses resulting in shattering. Crops that are subject to a hot sun by day and dew at night, accompanied by wind or rain, may be subject to higher shattering. Beachell, et al. (1964) reported that if crops lodged on the field, shattering losses other than by handling was not a problem, but varieties prone to shattering which resisted lodging could shatter grains during heavy winds and rains.

Shattering due to handling is low in the preharvest operation. Farmers generally keep away from the fields close to maturity. Grains would shatter during spraying or weeding operations in the fields. However, such operations are not performed at the time of maturity unless emergencies occur. Grains shatter if plants are disturbed by bird and animal movement. High wind velocities bring plants and panicles in contact with each other resulting in abrasion and then grain shedding. Wanders (1974) reported that losses from shattering on standing plants increased from 25 to 75 kg/ha, or from 1 to 5.25 percent after a 16 day delay period, Figure 3.4.

Numerous methods have been used to test the ease of shattering in different varieties of rice. Grain has been collected in cloth sacks during the process of transportation and drying. Hanumantha Rao (1935) used a 1 kg cylinder and rolled it over panicles placed on an inclined board. The percentage of dropped grain was calculated from the dropped grain. Ito, et al. (1968) reported that grain shedding characters were calculated from the strength required to detach grain from its pedicel by using an unbonded gauge type transducer and an automatic null balancing recorder. Forty-eight cultivated varieties of paddy rice were used, taking three panicles of each, at about 50 days after heading. The degree of grain shedding was classified into six classes, varying from 230g to 75g. Singh and Burkhardt (1974) reported that the spikelet attachment strengths of different varieties measured with an Ingstron Testing machine varied from 241.8g to 33.9g. The

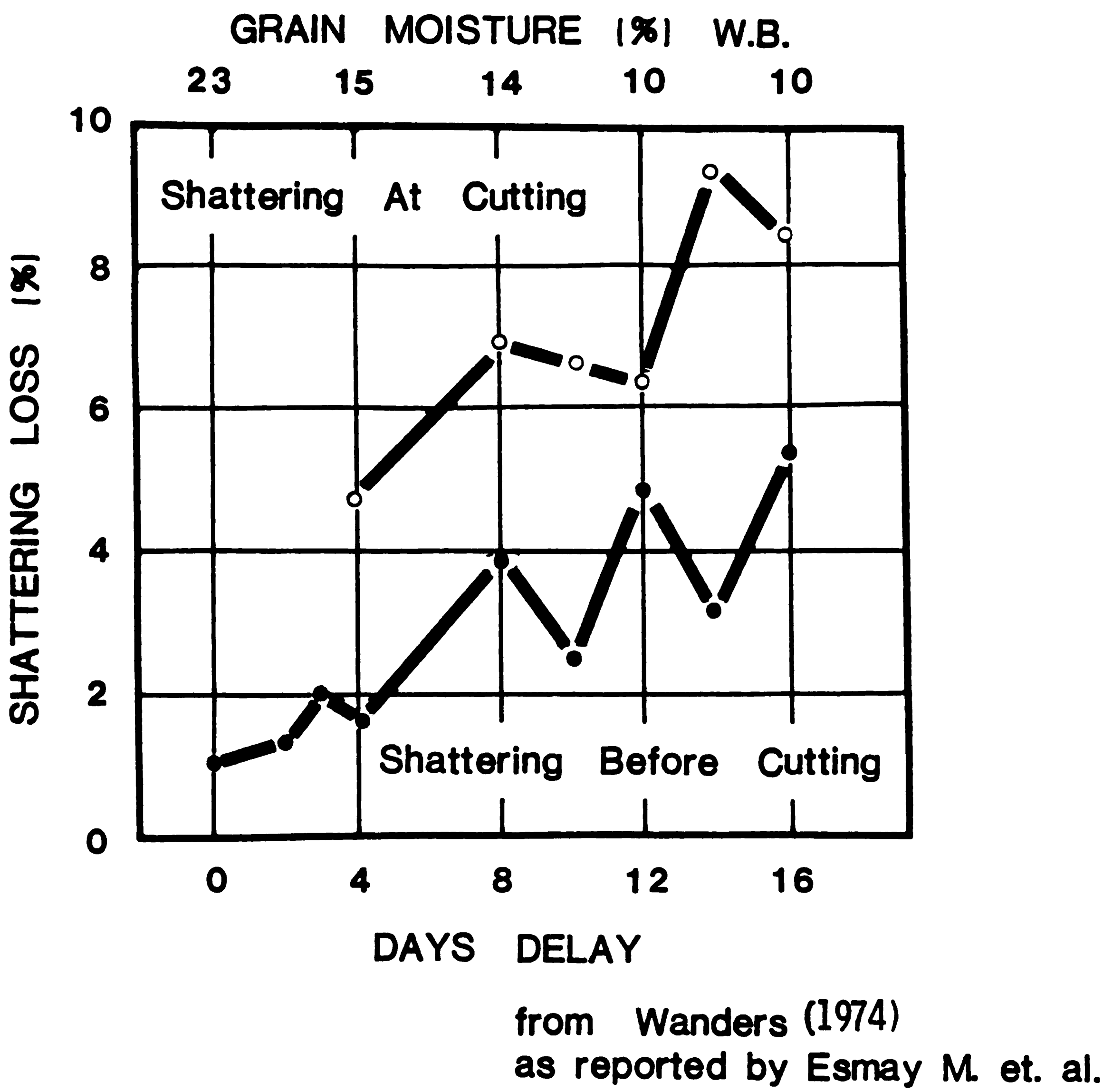


Figure 3.4 Effect of Delay in Harvesting on Shattering Loss by Plants in the Field and at Cutting Time for Variety D52-37

differences in attachment strengths were attributed to genetic characters. Similar results were obtained by Burmistrova, et al. (1956) where the strengths varied from 222g to 62.3g.

Te-Tzu and Bardenas (1965) classified shattering into tight (few or no grains removed), intermediate (25 to 50 percent grains removed), and shattering (greater than 50 percent grains rempved). This method was used for large scale evaluation studies. A panicle at the hard dough stage was grabbed with the palm of the hand and a gentle rolling pressure applied. The percentage of shattered grain indicated the shattering character.

Figure 3.5 illustrates the interactions between different factors affecting the shattering qualities of the rice plants.

b) Lodging.

A prime factor contributing to the reduction in the percentage of ripened grain is lodging. Lodging of rice crops before harvest is a serious problem for rice harvesters throughout the world. Lodging may be a result of environmental conditions or specific to grown varieties. The use of nitrogen responsive varieties with high nitrogen fertilizer applications and improved cultural practices have increased yields in certain varieties, while in some the use of high doses of nitrogen have increased their

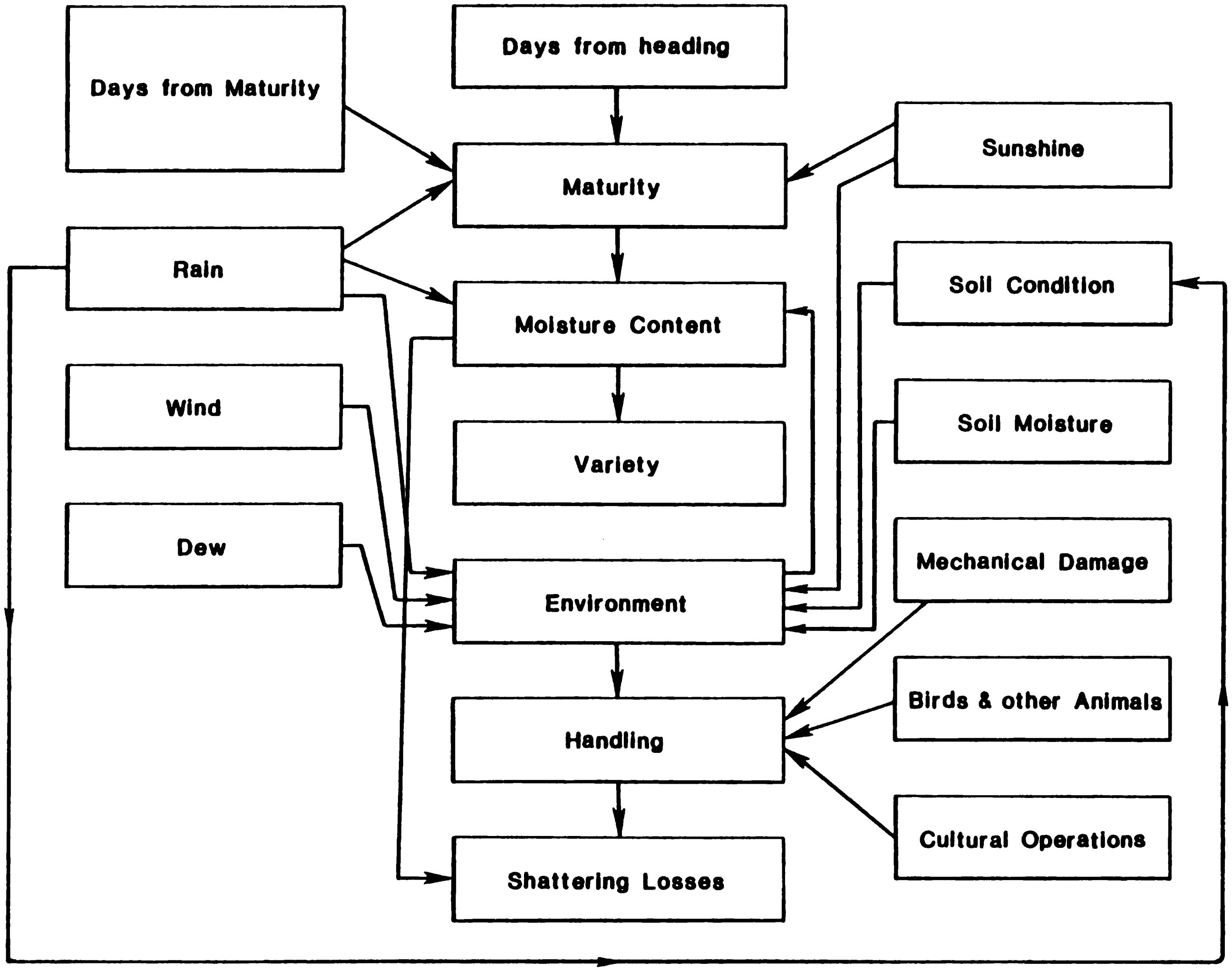


Figure 3.5 The Influence of Different Factors Contributing to Shattering Losses

susceptibility to lodging. The rice crop usually lodges before maturity and at times before flowering. Lodging limits the use of harvesting machinery and increases the labor costs during the harvesting process. Beachell and Jennings (1964) report that studies made at the International Rice Research Institute have shown yield reductions of up to 75 percent when rice lodged 30 days before maturity.

The lower internodes of varieties susceptible to lodging are longer than average. Tsunoda (1964) reported that the varieties adapted to low fertilization tend to have thinly elongated stems which were apt to bend or lie horizontally, while the culm and the leaf sheath were liable to lodge at ripening. Low nitrogen responsive varieties become leafy with heavy nitrogen application. Tanaka (1964) reported that mutual shading caused by the leafy growth reduced the light intensity at the base of the plant and accelerated the elongation of lower internodes. The culm gets thinner and the plant gets top heavy resulting in lodging. Mutual shading may also occur with closer plant spacing and an increased planting density. The resulting elongated internodes will again succumb to lodging.

Sugimoto (1965) reported that certain morphological characters effected the lodging of rice and its lodging index. The weakening of the internodes closer to the ground surface, or less than 15 cms above the ground surface were observed. In many studies it was shown that elongation took place at the fourth node. These internodes were longer and narrower when compared with sound rice plants. The bending moments and breaking strengths of the third and fourth nodes increased after heading and reached a peak at the dough stage, decreasing again at maturity, Figure 3.6. The lodging index given as,

Bending moment/breaking strength X 100

(where the bending moment = the total length above the fourth node X fresh weight above node 4)

increased gradually after the heading stage. In Japanese rice plants a lodging index of 200 was reported to be the danger limit. In tested Malaysian rice varieties a lodging index of 200 was reached at the time of heading or at the dough stage. These varieties had a greater possibility of lodging after heading. Due to changes in culm quality, withering, loss of moisture and gradual senescence, Matsuo (1952) reported that plants were most liable to lodge as they approached maturity.

Internodes are low in inorganic substances, but high in cell wall building material and starches. About a week after heading, the stored starch begins to migrate from the lower stem area to the upper parts, including the panicles. Translocation of nutrients to the grain takes place during maturity and weakens the lower internodes of the plant. Kono and Takahashi (1961) reported that potassium deficiency was seen to decrease the accumulation of starch and cell wall substances essential for the strength of the stem. A

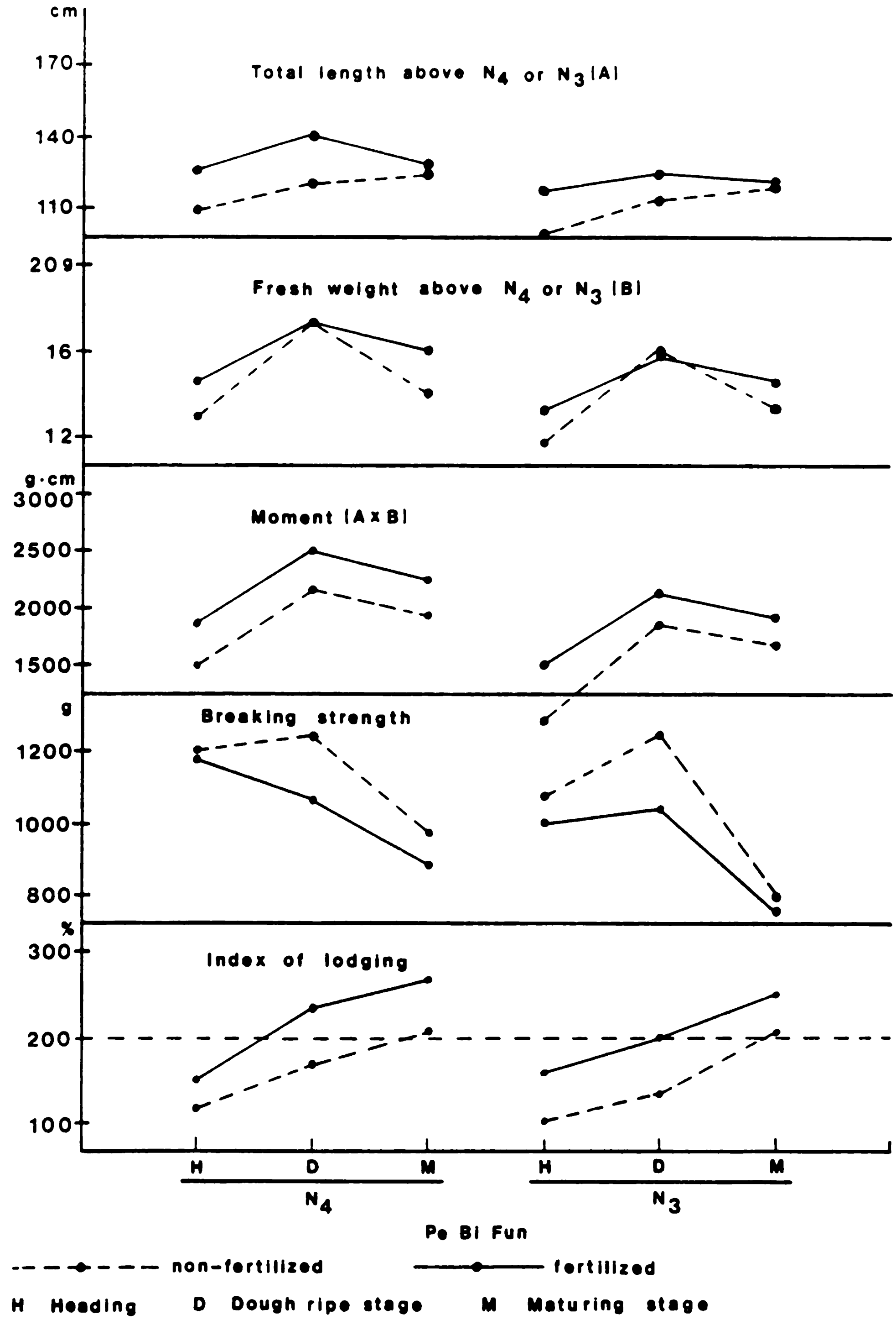


Figure 3.6 Changes in Index of Lodging after Heading (From Sugimoto 1965)

close correlation between the potassium content of the base and the breaking strength of the stem is illustrated in Figure 3.7.

Tanaka (1964) reported seasonal variations in lodging where the peta variety was inclined to lodge less heavily before flowering in the dry season. The lodging of peta during the rainy season was related to the remarkable elongation of the lower internodes before the panicle initiation stage of the plant.

The incidence of lodging in combination with the higher frequency of rainy days during the harvest time results in higher harvesting risks. The degree of seed dormancy varies from zero to 6 months and is related to variety and climate. Wanders (1974) reported the risk of sprouting at harvest in lodged, poorly drained fields was high and resulted in greater grain losses.

Figure 3.8 illustrates factors affecting lodging either individually or in interaction. Losses in grain due to lodging contributes to the losses in the total post production system.

c) Bird and Rodent Damage.

Vertebrate pests damage rice continuously from planting to harvest by destroying large areas of rice farms and substantial proportions of the harvested grain. Birds and rodents are the most serious vertebrate pests in many

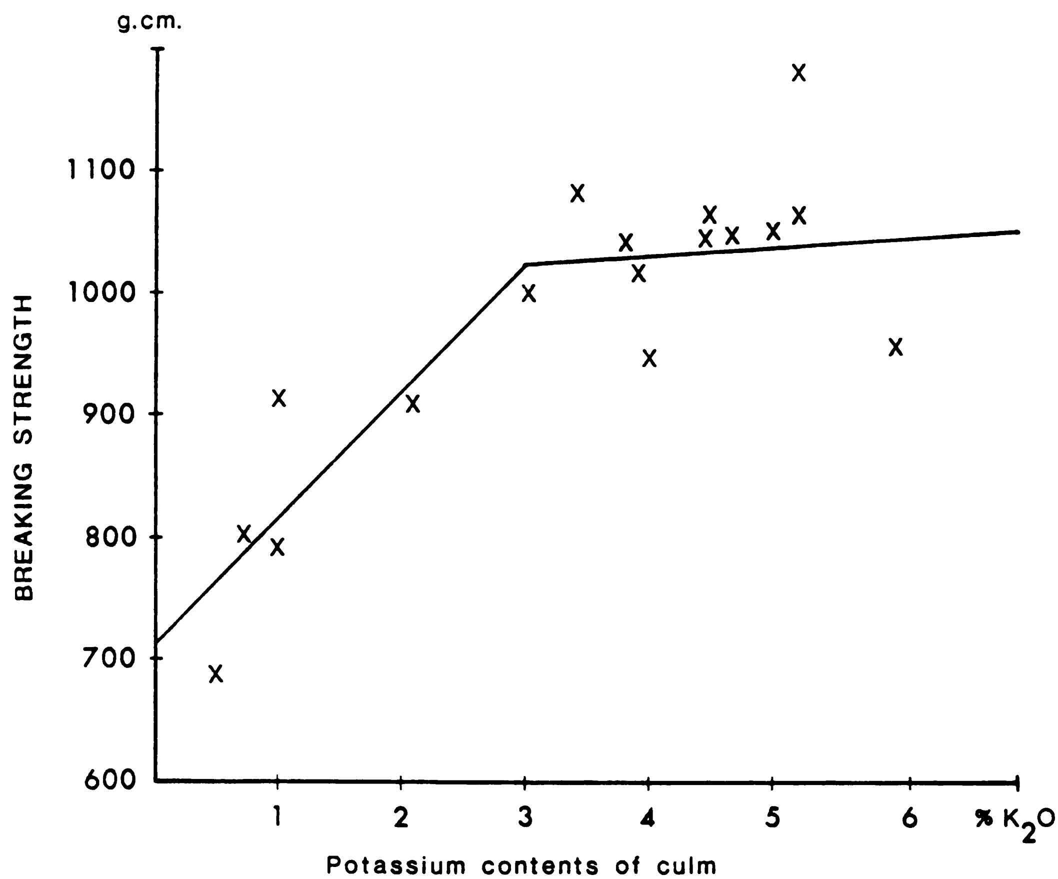


Figure 3.7 Relationship Between Breaking Strength of Stem and Potassium Content of Culm (From Kono and Takahashi, 1961)

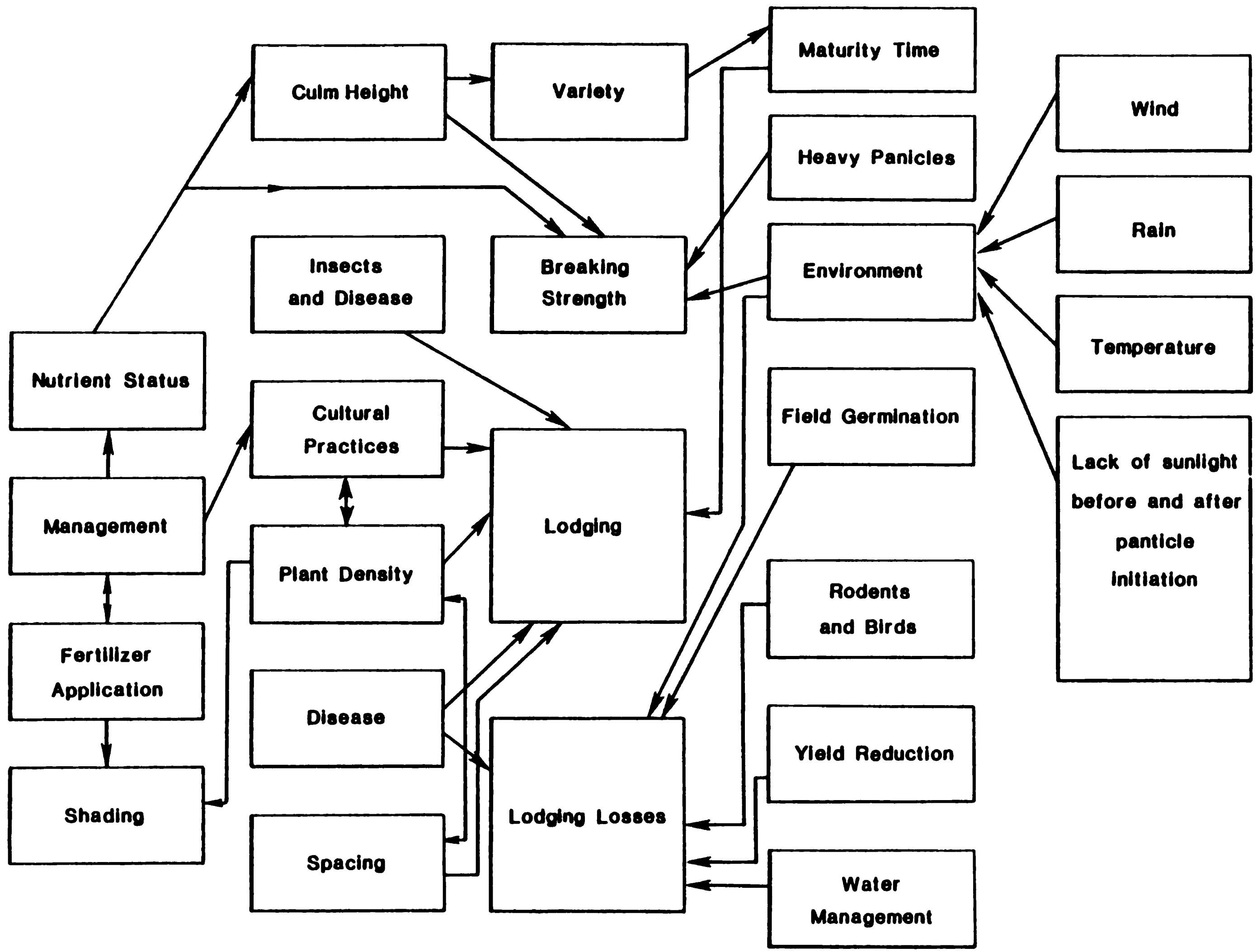


Figure 3.8 Losses Due to Lodging as Influenced by Environmental and Managerial Functions

countries, which include Central and South America, Africa and Asia. Funomilayo and Akande (1977) reported that total preharvest and postharvest losses caused by vertebrate pests on rice were estimated to be 40 percent in Southwestern Nigeria.

Bird and rodent damage from grain-filling to ripening is important because it contributes to the losses in the preharvest phase of the subsystem.

Rice probably suffers more damage by pests than other tropical crops. In Venezuela, migratory birds were reported by Grist (1975) to be the greatest cause of losses in rough rice by pests. The Pans Manual (1974) states that in Africa over 50 species of birds were responsible for damaging planted paddy. Birds may cause damage either by picking fallen grains or by attacking the panicle from flowering to grain ripening. Blackbirds are a serious pest in California, where large flocks pick up broadcast grain before irrigation. Some birds, such as the weaver birds, were observed by Funomilayo and Akande (1977) damaging rice during the flowering and fruiting periods in Nigeria.

Birds puncture and suck the milk in the developing grains. Grains damaged at this stage remain empty and are blown away during the cleaning operation after cutting. Grain damage by birds is very common and can be very severe in certain areas. Birds will eat the rice at maturity and drop the rejected hull onto the ground. Large areas of rice can be destroyed at this stage, depending on the incidence of birds and the stage of maturity of the rice plant. Grains of rice may be dropped while birds attempt to eat them. At maturity and thereafter, a majority of grains drop due to the impact of the birds alighting on rice stems and mature panicles. Shattering due to bird infestation is another contributing factor towards losses at preharvest.

Rats attack the plant at all stages of its growth and are very destructive to both rough and milled rice. The value of crop damage by rats before harvest in the Philippines was estimated at ₱ 40,000,000 in 1958, (Training Manual IRRI, 1970). Prakash (1974) reported that in paddy fields of Uttar Pradesh and Madras in India, 7.1 to 21.5 percent and 5.2 to 65.3 percent of plant tillers respectively were destroyed by rodents, reducing the yield of rough rice to 59.5 percent and the yield of straw to 45 percent. Rodents dig up and eat the freshly sown rice. At the seedling stage rats feed on the heart of the stem while the grain is eaten from the filling stage until harvest by felling the plant 5 to 15 cm above the ground level.

Rats cut the stem with a clean bite and chop the stem into small pieces. They may consume the inner tissues and, depending on the stage of maturity, attack the grain on the ground. Rats may live in burrows under lodged plants and feed on the grain within their reach. Lodging therefore increases the incidence of grain damage by rats.

3.2. Harvesting -- Cutting Losses.

Harvesting is essentially by hand in Asian and African rice producing countries. Mechanical harvesting is practiced in a limited manner whereas in some countries where labor availability is low mechanical harvesting has increased in popularity. A period in plant development where substantial losses in grain occur is that between the attainment of maturity and the ripening of grain before harvest. Grain losses at cutting are influenced by the method of cutting, time of harvest, environmental conditions, availability of labor, etc. The condition of the harvested grain determines the subsequent quality and quantity of grain at storage and processing operations.

The traditional sickle is used for cutting paddy straw in many countries. In India, Korea, Sri Lanka and Taiwan harvesting is essentially by sickle, while in the Philippines and Indonesia sickle harvesting is performed along with panicle harvest. Collier, et al. (1973), Herrera (1975) and Esmay, et al. (1977) report that a traditional practice in many parts of Indonesia, the Philippines and some of Malaysia is to clip the panicle from the rest of the straw with a sharp knife. Pillai (1958) reported that due to a dearth of labor and a lack of transport facilities from the field to the threshing floor, certain cultivators of Orissa state cut panicles off the harvested sheaves which were left to dry in the field. The panicles were then stacked and threshed at a more convenient time. Koga (1977) reported that about 15 percent of the harvesting operations in Japan up to 1975 were by hand, and of the 85 percent harvested by machine, 40 percent were with small combine harvesters.

a) Cutting by Sickle.

Hand sickles are used to cut stalk with grain about 10 to 25 cm above the soil surface. The sickle varies in shape and blade angle in different countries, having either a smooth or serrated self-sharpening edge. Grist (1975) states that although the shape of the blades differ their function is essentially the same. The plant is cut either by a slicing action with the smooth edge or a tearing action with the rough, serrated edge. Khan (1976) reports that the serrated sickle combines a slicing and sawing action and restricts sliding of the plant on the blade edge, helping to retain the plant on the blade for adequate cutting.

The failure of the plant structure due to compression, tension and shear results in a tearing action caused by the slicing effect. Esmay, et al. (1977) reported the findings of Chancellor (1958) and Burmistrova, et al. (1963) where the energy required for cutting varied with the moisture content, plant variety and the diameter of the plant straw. Burmistrova, et al. (1963) further showed that the shear resistance per unit cross sectional area of the stem decreased with the distance of the cut section from the base of the cut plant and that the resistance to cutting was inversely proportional to the plant moisture content. Esmay, et al. (1977) stated that Rajput and Bhole (1973) were reported to have found similar results where the cutting force per unit cross sectional area was found to increase nonlinearly with the increase in distance from the base of the plant. Maturity of the plant accompanied by the decrease in moisture content and increased buildup of lignified cell wall material may have caused the variations in the cutting forces observed.

Curfs (1974) reported that the capacity for harvesting, defined as the weight of rough rice harvested per man hour, varied with the environment in which the crop was grown. Specific varieties grown under irrigated conditions showed an optimum harvesting capacity of 40 to 60 kg of rough rice per hour, at 30 to 35 days after 50 percent heading, in contrast to the upland condition where the capacity decreased from 33 to 22 kg/hr with delayed harvesting. The reason for the decrease in capacity was probably due to the straw of varieties grown in upland conditions senescing quicker and causing difficulties in sickle harvesting. Esmay, et al. (1977) reported that an average skilled person could harvest standing paddy at a rate of 0.01 ha per hour or 40 to 50 kg of stalk per hour and that saturated soils at harvest reduced the cutting rate, while lodging decreased the rate by

50 percent. The rate of harvest can vary depending on the availability of labor, number of persons, their experience, physical condition of the knife blade and the time at which the harvest is performed. The rate of harvest in the morning may be higher than that in the afternoon when harsh environmental conditions cause fatigue and decrease the efficiency of the harvesters.

b) Panicle Harvesting.

Grist (1975) and Contado and Jaime (1975) observed that the traditional method of panicle harvesting is used in many countries. A small knife two to six inches long is fixed crosswise on a short wooden block and referred to as "pisau penaui" in Malaysia, "yatab" in the Philippines, and "ani-ani" in Indonesia. The knife is concealed on the harvesters palm. Using the knife, the finger is bent around the stem of the plant. The panicle is then drawn onto the blade, severing it from the stalk about 20 cm below the panicle. When a few panicles have been cut and retained on the cutting hand, they are placed on the other hand to accumulate into a larger bunch. The bunches are then placed in a basket to be transported off the field.

The harvesters in the village are mostly women from within the villagers and from neighboring villages. This method of harvesting utilizes a large number of persons to cut and carry the paddy. Collier, Wiradi and Soentoro (1973) reported that in some instances as many as 500 persons may be employed per hectare. Esmay, et al. (1977) stated that a skilled person is able to harvest 10 to 15 kg of panicle stalk per hour. The traditional practice is for farmers to pay the harvesters with a share of the crop. The shares are seven, eight or nine for the owner, to one for the harvester; the division being made by bundles and not by weight.

These methods of harvesting seem to be undergoing significant changes. A contributory factor is the pressure of population on land. Individual land sizes are becoming smaller as lands are being divided and subdivided from generation to generation. Farmers, therefore, find their shares getting smaller and smaller. However, farmers are still quite powerless in controlling the division of shares. Sickle harvesting, however, has been adopted in many areas, especially due to the introduction of high yielding varieties.

Grist (1975) indicated that the advantage of the ani-ani method was the high degree of selection leading to the exclusion of immature grains and impurities, while obtaining a maximum crop from badly lodged plants. Losses, however, have been reported by Esmay, et al. (1977) to be from 5 to 10 percent of the total yield. With the adoption of improved varieties, the losses at harvesting due to shattering may increase further. The use of the sickle for harvesting may reduce the potential losses in the new high yielding varieties, but the social implications arising from the change in harvesting methods are important factors to be considered in effecting such a change.

Losses in the cutting operations described above are influenced by the movement of people on the field. A higher rate of cutting or an increase in the number of people performing the operation will lead to more handling losses, influenced by the maturity of the crop. Losses may increase in the late afternoon when harvesters, in trying to complete a given section, increase the harvesting capacity at the expense of high cutting losses arising from increased handling and a faster harvesting rate.

3.3. Time of Harvest.

Perhaps the most important factor contributing to the losses both in quantity and quality of grain at harvest is the time at which the cutting operation is done. The time of harvest influences shattering losses for different handling operations, losses due to birds and rodents and losses at the final processing stage.

Farmers tend to keep the standing crop on the field until complete maturity so that field drying is complete at the time of harvest. This practice eliminates the need for drying facilities and eases the threshing operation, where dried grain separates easily from the panicles. The difficulty in determining the optimum time for harvest is enhanced by the uneven maturity of the standing crop, which makes it difficult for farmers to decide whether cutting should be done when all panicles mature or whether a certain percentage of the panicles attain maturity. Delayed harvesting results in the shattering of grain before harvest. It also leads to losses due to bird and rodent damages. Delayed harvesting and attempted field drying has adverse effects on the final grain quality where the percentage of cracked grain or "sunchecks" increase with a decrease in grain moisture.

Arora, Henderson and Burkhardt (1973) observed that internal skin cracks develop before harvest in rice kernels in the field. Periodic wetting and drying causes grains to crack if paddy is not harvested before grains are fully mature. Grain at maturity usually contains about 24 percent moisture and by the end of a hot day the moisture content could be reduced to as much as 14 percent, to rise again at night with dew. Interruptions in drying during the day could be brought about by rain. Grist (1975) and Smith and Macrea Jr. (1951) reported that the periodic alternate loss and absorption of moisture by grain causes the development of internal cracks in the grain. The absorption and desorption of the rice grain with regards to moisture is instrumental in causing the grain to crack or "suncheck". The effect of sunchecking is seen in the milled quality of the rice. Burmistrova, et al. (1956) reported that the factors affecting cracked grains other than harvesting machines were 1) fluctuations in moisture regimes during growth, 2) water temperature, 3) variation of air temperature and humidity during harvest and drying, and 4) the length of windrow drying. Coyard (1950) indicated that dew had little effect on broken grains; however, a marked difference was observed on overripe harvesting stages. Langfield (1957) reported that in both long and short grained varieties, increased breakages of rice grain resulted from delayed harvesting and a decreasing moisture content. Wanders (1974) reported the increase in the percentage of sunchecks from 10 to 98 percent within a period of five weeks from maturity, Figure 3.9.

Losses in grain at different stages of delay have been studied by many researchers. Ruiz (1965) observed that losses at a week before maturity was 0.77 percent, at maturity 3.35 percent, one week after maturity 5.63 percent, two weeks after maturity 8.64 percent, three weeks after maturity 40.70 percent and four weeks after maturity 60.46 percent. Wikramanayake and Wimberly (1975) showed an increase of 635 to 725 kg of paddy per acre, harvesting the crop at 28 to 22 percent moisture over harvesting at 14 percent. Harvesting earlier resulted in less yield and poor quality where most grains were shriveled and chalky. Harvesting too late resulted in grain loss due to shattering and bird and rodent damage.

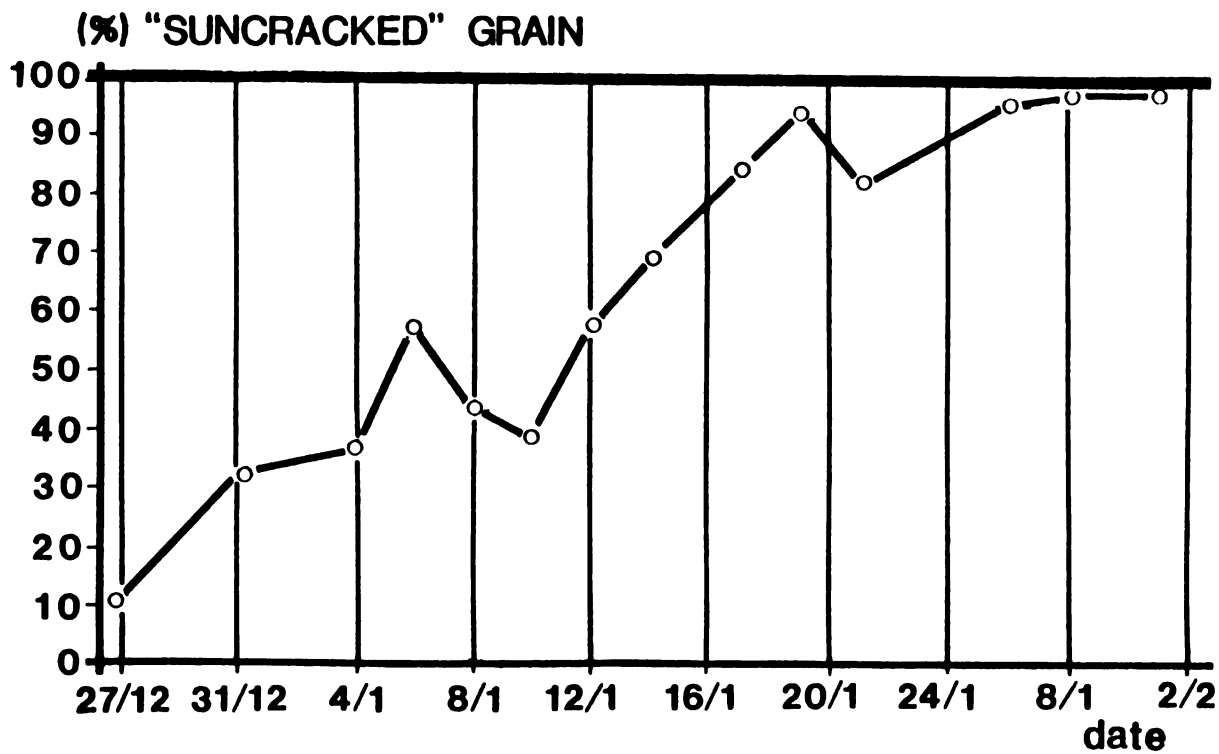


Figure 3.9 Percentage of Sunchecks with Delayed Harvesting (From Wanders 1974)

The time of harvest influenced the head rice yield at milling. Bhole (1970) observed a head rice yield of 60 percent (raw rice) for paddy harvested at 24.4 percent moisture and 55 percent for 15 percent moisture for variety ADT-8, whereas the head rice yield of 59.64 percent was recorded for IR-8, harvested at 24.8 percent moisture while its yield reduced to 42.42 percent when harvested at 15 percent moisture. Huysmans (1965) reported the decrease in percent of head rice with increased delays after maturity. Three varieties grown in Burma in 1962-63, C28-16, A50-11 and D17-88, were studied. The head rice percentage for grain harvested on the 30th day and the 50th day after 50 percent flowering were found to be 55.1 percent and 37.8 percent for C28-16, 48.4 percent and 5.6 percent for A56-11, and 55.8 percent and 47.9 percent for D11-88. Sunchecks were seen to increase from 5.8 to 25.5 percent, 17.9 to 75.6 percent, and 6.1 to 9.5 percent respectively for the three varieties. Similar observations regarding the losses in head rice percentage with delayed harvesting were made by Khan, et al. (1973). Chung, Kang and Lee (1977) who studied the effect of harvest dates on the head rice yield of Tong-il and Akibare varieties grown in South Korea arrived at similar results.

The optimum harvest time determines the quality and quantity of the final product. Assessing the correct stage is important and is governed by the evenness in maturity, weather and labor availability. The complexity of climatic conditions present in Southeast Asian countries have a strong influence on the harvesting and threshing methods. Nichols (1974) reported that rainfall patterns vary within countries such that harvesting and threshing may be performed under adverse conditions while areas with little or no rainfall have ideal conditions for those operations. Adverse weather during harvest affects its operation at the optimum time. The operation is delayed until a favorable day is available to harvest. Similarly, non-availability of labor at harvest affects the harvesting operation at the optimum time. If both conditions are favorable a decision on the optimum time for harvest has to be made.

Pan (1956) indicated that maximum yields could be obtained by harvesting rice at 40 days after flowering. The fact that the moisture content of the paddy grain is the best index for determining the optimum time of harvest irrespective of varieties and dates after heading is reported by Esmay, et al (1977). As a general rule of thumb, the optimum moisture content for harvest is reported to be about 20 percent wet basis. Ten Have (1961) observed a moisture range of 17 to 21 percent for the maturity of seven different varieties under trial. Wikramanayake and Wimberly (1975) found that 28 to 22 percent moisture gave maximum yield under harvesting conditions in Sri Lanka. Khan (1976) suggested that harvesting should be carried out when the grain on the upper portion of the panicles were clear and firm and most of the grain at the base of the panicle were in a hard dough stage. At this time at least 80 percent of the grains were straw colored. Vo-Tong and Ross (1976) made similar suggestions and indicated that the remaining 20 percent were in the hard dough stage at the time of optimum harvest.

Although the optimum time of harvest gives rise to maximum yields, certain drawbacks could occur when practiced with available technology under actual farm conditions. Farmers may not have any drying facilities within their farming areas. If the harvest is made at the suggested optimum time, the moisture content at harvest is high, resulting in a need to dry the grain to storage moisture content. However, if drying facilities are not available the farmers are unable to dry the grain to the desired moisture content. The farmers therefore have to depend on field drying before the harvest operation is performed, resulting in a delay beyond the optimum cutting time. Similarly, the available threshing facilities may not be acceptable for threshing high moisture paddy. Farmers prefer to dry the paddy on the field and help ease grain removal with existing threshing technologies. The harvest is then delayed beyond the optimum period. It is necessary, therefore, to consider the effects of timely harvest on the other farm operations before actually implementing optimum cutting time. The factors influencing losses at cutting are illustrated in Figure 3.10.

3.4. Laying and Bundling.

These operations may vary from country to country. The basis of laying the cut stalk is to field dry the paddy prior to transport and subsequent threshing. The stalk may be left on the stubble for a day or two so as to facilitate field drying. The duration of stalk drying, however, depends on the moisture content at cutting. If the stalks are cut early, the moisture content is high and the stalks are left on the field for more than a day. When the stalk is cut at a stage beyond maturity and the moisture content is low, the usual practice is to leave the sheaves overnight.

Field drying is subject to uncertainties of weather. If the weather if favorable, field drying can be an effective way of reducing the moisture content of the grain prior to threshing. If weather conditions are unfavorable, the cut sheaves have to be transported and stacked at high moisture contents.

Experienced harvesters have windrows on the path of harvest facilitating easier collection and reduced handling losses. In poorly harvested fields, the bundles are irregularly placed and contribute to greater handling losses. The losses in the laying and bundling operation are influenced by many factors, of which the act of laying the bundle, the

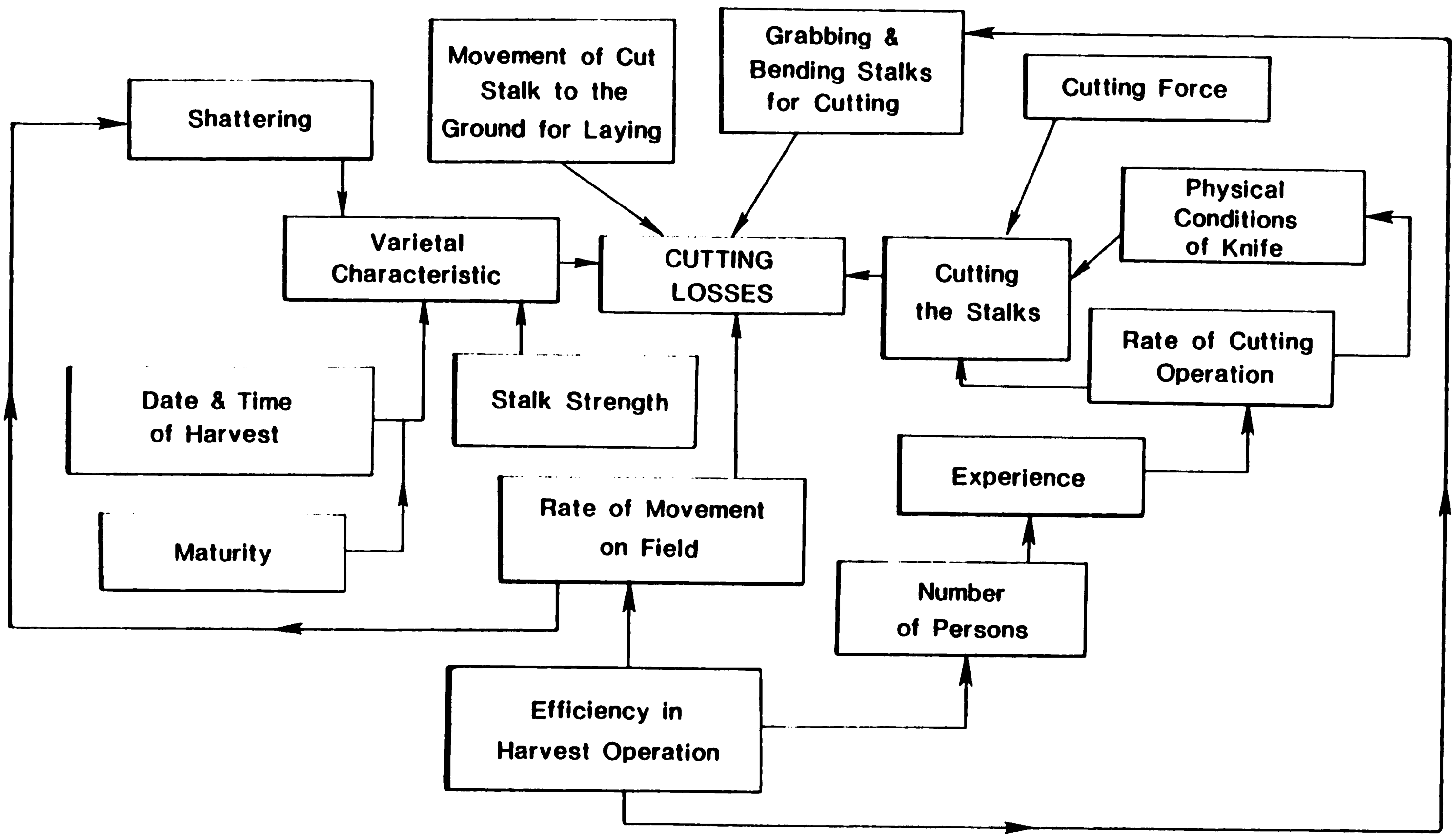


Figure 3.10 Factors Influencing Grain Loss During the Cutting Operation

condition of the ground surface and environmental factors are of prime importance, Figure 3.11.

The duration of field drying may affect the quality of the rice grain at milling. Dobelmann (1961) studied the effect of drying methods (before threshing) on the milling yield and quality of milled rice. The paddy was cut, bundled and stacked at different nightly intervals. The grain was dried and the milling quality determined. Considerable losses in milling recovery was seen with delayed stacking up to nine days. A 15 percent increase in broken grain was seen after a delay of one night. Highly significant differences in percentage of cracked grain was noticed between stalks dried in the shade and the sun. The percentage of broken grain was much lower when stalks were dried in the shade. Coyard (1950) reported that occasional wetting did not harm the quality of rice if the stalk was dried in the shade. However, if the stalk was dried in the sun and experienced occasional wetting, the percentage of broken grain increased considerably.

3.5. Field Transportation.

The bundled stalks after being field dried are transported to the threshing floor. The transporting distance varies depending on the location of the threshing floor. The usual practice is to carry the bundle on the head, but farmers not owning threshing floors may have to transport

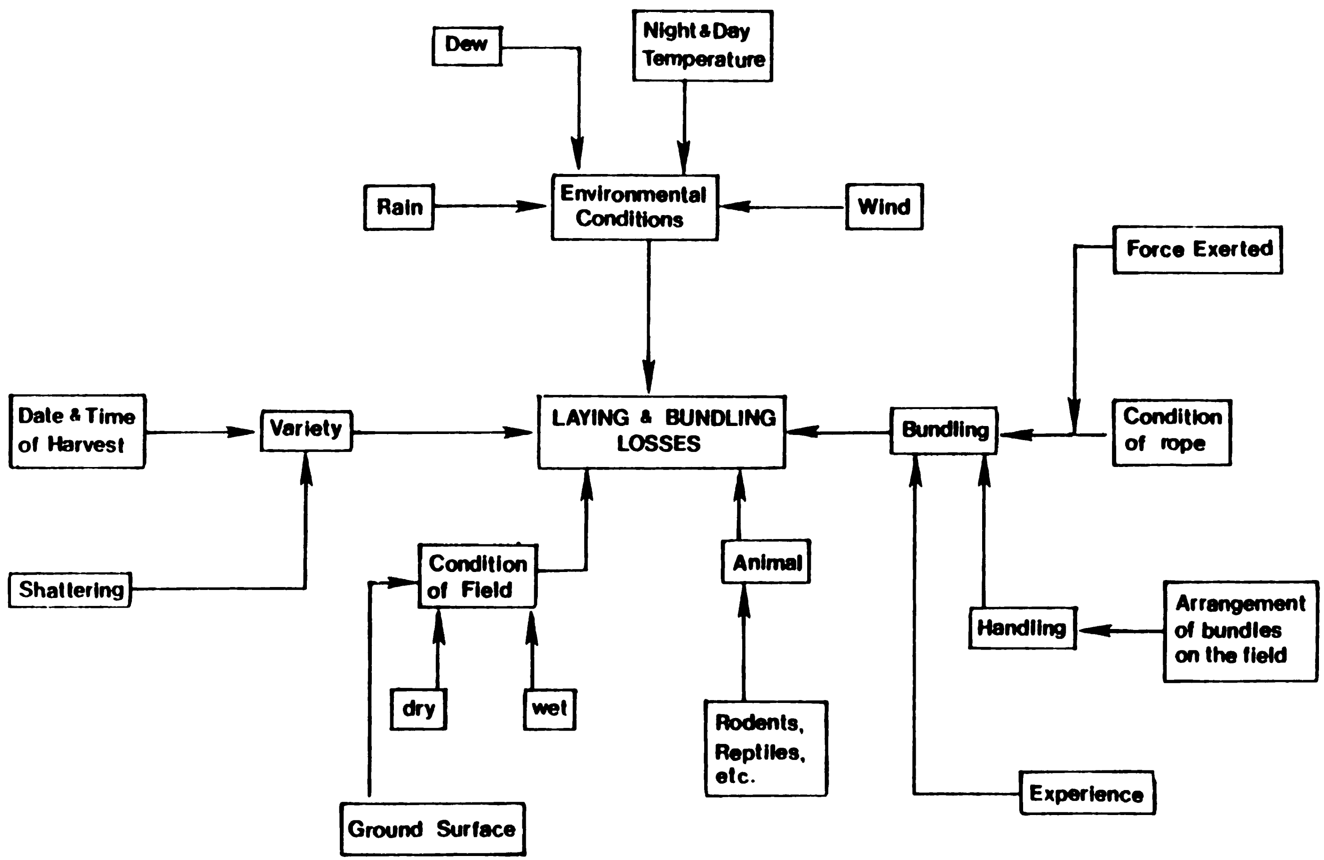


Figure 3.11 Factors Influencing Losses in the Laying and Bundling Operation

the cut stalk considerable distances in bullock carts. However, the stalk is initially head carried to the bullock carts.

Curfs (1974) reported the use of racks and two-wheeled tractor trailers in addition to the use of manual transportation. The transportation capacity as measured by Curfs (1974) in kg of rough rice/100m/hr, varied from about 50.9 kg at 20 days after 50 percent heading to about 67.8 kg at 55 days. The irrigated crops showed a higher transportation capacity as the crop dried with delayed harvesting. The upland crops, however, did not show a marked difference in transportation when measured at the respective dates. Transport of stalk with a rack carried by two people did not increase the capacity when compared with manual transportation. The use of the trailer, however, made transportation about two times faster than manual transportation. Jacobi (1974) showed that on an average 45 man hour/ha are needed to transport bundles manually over a distance of 250 meters or greater. Curfs (1974) indicated that in general, transportation of a rice crop (over 100m) took about the same time as the harvesting operation.

Losses in transportation are influenced by many factors, Figure 3.12. Curfs (1974), who studied losses in grain due to transportation as a percentage over a total yield, indicated an increase in grain loss with delayed harvesting. Shattering characteristics of different

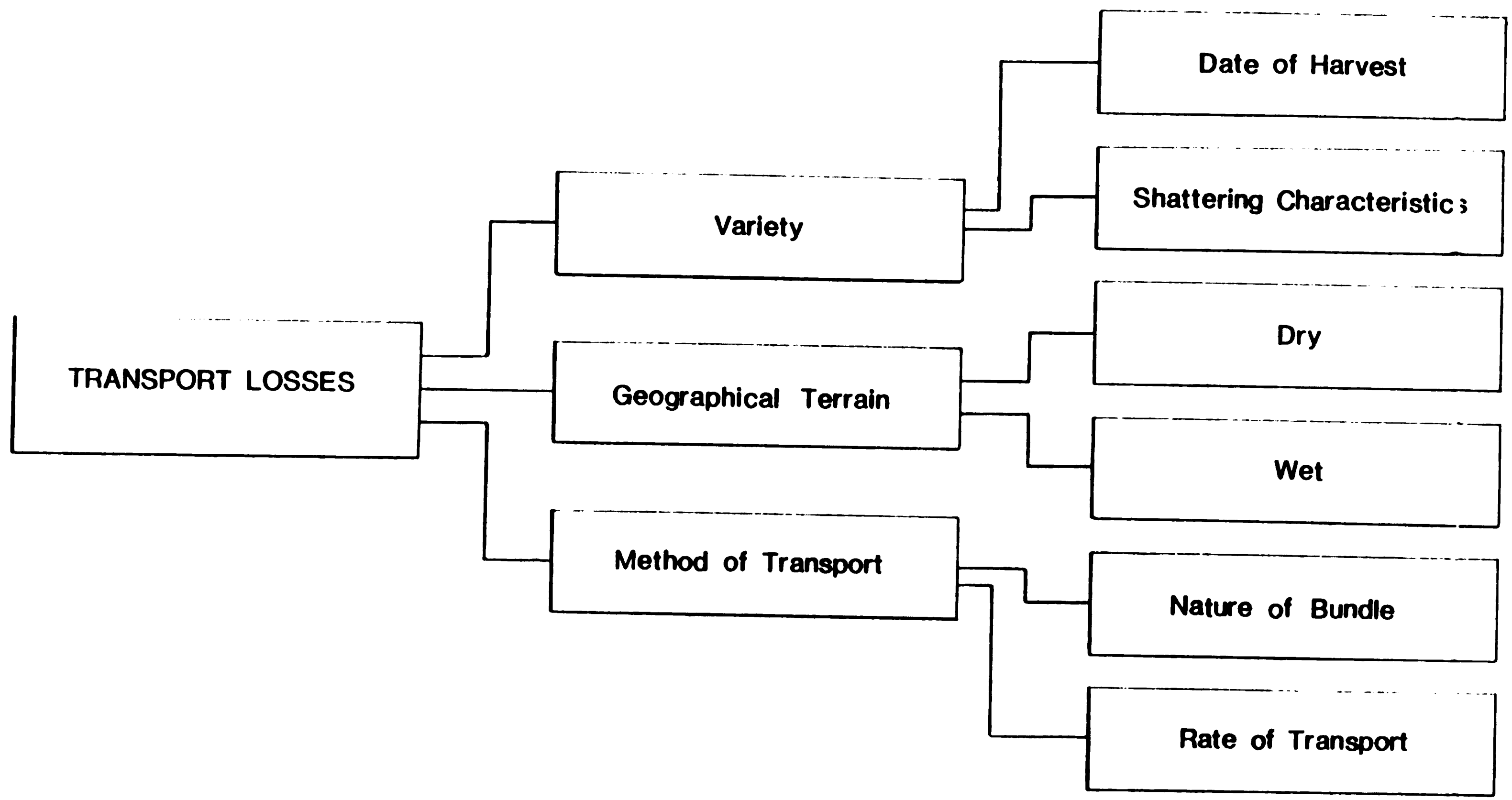


Figure 3.12 Factors Influencing the Losses of Grain During Transport

varieties influenced by the stage of maturity at which the harvest is performed are perhaps the major factors contributing to the grain loss. The terrain of the farm area influences grain loss in that movement through rough terrain results in a greater movement of panicles within the bundles at transport. The movement of panicles simulate a threshing process resulting in detached grains.

The highest losses in the total handling operation is from the transportation process although in some farming areas bundles are wrapped in mats to prevent grain from falling. This practice, however, is limited to very small land areas where family labor is involved in transportation. The use of the pedal thresher in the field reduces the distance to which bundles have to be transported and therefore reduces the losses in transportation.

3.6. Threshing.

Threshing methods vary between and within countries. Threshing is an act whereby the grain with its adhering husks or glumes is separated from the stalk by use of manual or mechanical forces. Khan (1976) reported that separation is achieved by three methods: 1) rubbing action, 2) impact, and 3) stripping. Rubbing occurs when the paddy is threshed by men, animals and tractors. The impact method is most popular and could either be an action of beating sheaves on a stationary object or holding the straw stationary while the grain is removed by impact of the panicle on the rotating spikes or wire loops of a mechanical threshing drum. Stripping is where the grain is separated from the plant while on the field. Some stripping occurs with impact threshing in conventional threshers while actual field stripping has been tried out by centrifugal threshers and strippers without much success commercially.

Manual threshing by trampling; beating on tubs, threshing boards or racks; and flail threshing is common in many rice producing countries. Threshing by foot is performed by spreading the stalk on a hard surface either in or off the field and providing rubbing forces by walking on the stalk until the grains are loosened. In manual treading preference is given to slightly damp awnless paddy as the stalks would be less injurious to the feet. Foot threshing, however, is extremely slow and, as reported by Esmay, et al. (1977), may have a capacity of about 30 to 40 kg/hr.

Grist (1975) reports that flailing and beating is still practiced in many countries. In Malaysia stalks are beaten on a rack and the grain collected underneath. The racks are portable and moved around the field during the threshing operation. Sheaves may also be beaten in wooden tubs on or adjacent to paddy fields. Inside the tubs, usually about the size of half a barrel, rests a ladder with rungs about 10 cm apart. The sheaves are beaten two or three times against the ladder and the removed grain is collected in the tub. A screen is placed around the tub to prevent grain from scattering.

The only mechanical equipment used for manually powered threshing is the pedal thresher which originated in Japan during the early stages of mechanization. This thresher is popular in Taiwan where a team of 5 to 7 men work each machine. The crew moves in a circle; while one or two men are threshing the others collect and bring new paddy bundles. The cylinder rotates at about 300 rpm and the inertia of the cylinder keeps the drum rotating as the men take turns pedaling the machines. Studies at IRRI indicated an output of 30 to 70 kg of paddy per hour, while in Taiwan, 60 to 65 man hours per hectare were required for pedal threshing with a capacity of 50 to 80 kg/hr, (Khan, 1976. The advantage of the pedal thresher is that it could be used on the field and thereby reduce potential losses during the transport of cut stalk to the threshing floor.

In some countries of which Sri Lanka is one, animal threshing is very common. Sheaves are brought to the threshing floor where they are stacked or sundried. At threshing the sheaves are laid two or three deep around a stake with the panicles towards the stake. Buffalos are driven slowly around the stake to trample out the grain. Grain damage is usually high due to the sharp impact forces of the animal hooves. Contamination due to urine and dung are also undesirable outcomes of this method. Jacobi

(1974) reported that 80 to 110 man hours/ha were necessary to perform this operation.

The use of tractor wheels for threshing has been practiced in some countries and is popular in Sri Lanka for custom threshing. The sheaves are arranged similar to that for animal threshing and the tractor is run over the sheaves for several hours depending on the harvested area. A threshing capacity of 640 kg/hr has been observed by Khan (1976) in Sri Lanka when two threshing floors were alternately worked with one tractor. The weight of the tractor wheels increase the percentage of broken grains although the capacity is higher than buffalo threshing.

Mechanically powered threshing machines are gaining popularity in many countries. Toquero, et al. (1977) reports that in the Philippines farmers appeared to prefer the mechanical thresher due to its high degree of availability (timeliness) and the ease of monitoring the threshing and distribution of the final product. In contrast to the traditional method which offered considerable opportunity for pilferage by those performing the threshing operation, mechanized threshing effectively consolidated control of the threshing operation. Mechanical power threshing is in limited use in Sri Lanka. However, from a sample investigation made during the course of this study, many farmers were encouraged by the idea of having mechanical threshers on a custom basis so as to perform timely threshing operations. In areas of high rice production, the limited availability of tractors or buffalos hindered the timely performance of the threshing operation. In certain instances farmers have to stack the cut stalk for weeks before threshing operations could begin. The farmers therefore showed willingness to utilize mechanical threshers on a custom basis in preference to experiencing delays arising from the lack of tractors and buffalos at threshing. Threshing machines to be used in this context, however, should be of intermediate capacity, be portable, non-labor saving and have adequate support facilities for repairs, etc.

Mechanically powered threshers may be equipped with one of the following types of cylinder and concave arrangement: 1) rasp bar with concave, 2) spike tooth with concave, 3) wire loop with concave, and 4) wire loop without concave.

Threshing machines may be the "hold on" type where the stalk is held over the rotating drum. A single cylinder machine is commonly of the "hold on" type and is basically a modification of the pedal thresher with the addition of a driving system powered by a small engine. Three types of "hold on" machines are in common use. 1) The engine driven modified pedal thresher as in Taiwan. The machines have no cleaning and grain separating mechanisms. The output of these machines is fairly low, but the advantage is that they are simple and could be manufactured in most Asian countries. 2) Japanese power threshers are equipped with a wire loop threshing drum and a regular cleaning and winnowing mechanism. Since they are of the "hold on" type they have a low capacity and a relatively high labor use. 3) Self-feeding automatic threshers are similar to the nonautomatic threshers except that they are equipped with gripping mechanisms which help feed the held stalk in a continuous layer into the threshing drum. The threshing output in this machine is high. In all methods the paddy stalk should be cut long so the stalk could be held and fed into the threshing machine.

The "throw in" type machines are of two types: 1) the through-flow, and 2) the axial-flow type. In the "throw in" type the paddy stalk may be cut short, since the paddy plants are fed completely into the machine. The through-flow machines are equipped with a cylinder and concave while some may have a separating and cleaning mechanism. The axial-flow thresher, developed at IRRI, combines threshing with air and screen cleaning devices. Khan (1976) states that the capacity is rated at 1 t/hr and because of its simplicity has had few operation and maintenance problems. Numerous threshing machines have been manufactured under different name brands, but all basically have similar loop, drum and concave arrangements.

Threshing losses are influenced by the variety, the method of threshing, the duration of field drying and the maturity of the crop at harvest. The threshing methods determine the percentage of cracked grain remaining after the threshing process. The duration of field drying and maturity of the crop at harvest determines the final milling output and percentage of head rice recovery.

Tractor and buffalo threshing gives rise to a high percentage of cracked grains. The paddy grain is subject to high forces arising from the weight of the tractor wheel and the hooves of the animals. Damages to grains may further be affected by the maturity at time of harvest. If the crop is left until the over-ripe stage, grain may become brittle and break during the threshing process. If grains are immature they tend to get crushed by the forces acting on them. Crops harvested at the optimum time may withstand the forces exerted by the tractor wheels and hooves of the animals.

Gupta (1963) reported that damages to grain by mechanical threshing could be due to improper concave and drum adjustment and drum speeds. Grains may be crushed and broken at the time of threshing. Similarly, invisible damage may occur on the grain which could be determined only by removing the husks by hand. Wanders (1974) reported that the percentage of unhusked grains broken inside increased from 25 to 49 percent from normal harvest time to late harvest respectively in variety D52-37 and 15 to 26 percent respectively in variety Taichung N.-1. In studies made by Curfs (1974) where the immature grain percentage decreased with maturity, broken grains and cracked kernels decreased from about 2.23 percent in variety TOX 7 to about 1.48 percent at 30 to 35 days after 50 percent heading and increased thereafter to 2.31 percent.

Unthreshed grain is a result of improper setting of drums and concaves. Percentage of unthreshed grain may be a function of the maturity at time of cutting, the variety being threshed and in the case of pedal and "hold on" power threshers, the length of stalk at the time of cutting. Figure 3.13 exemplifies the factors influencing losses at the threshing operation.

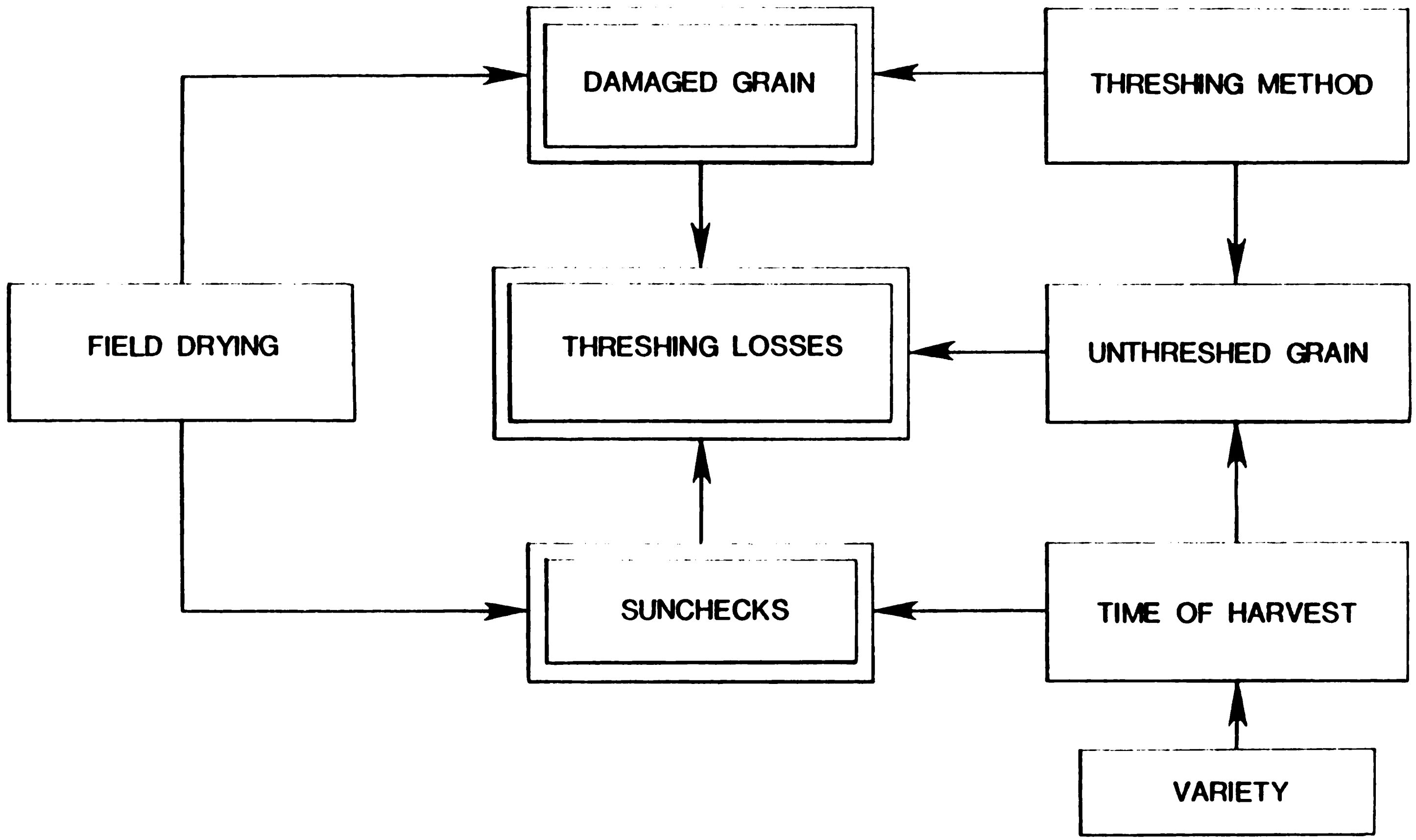


Figure 3.13 Factors Influencing Losses at Threshing

CHAPTER IV

ASSESSING POST PRODUCTION FIELD LOSSES

Field measurements of grain losses in the in-field post production system were made in the latter half of two cultivation seasons, the Maha and Yala. The Maha (wet season) extends from October through March while the Yala (dry season) extends from April to August. These two seasons coincide with the Northeast and Southwest monsoonal periods respectively. A major portion of the dry zone is cultivated only under rainfed conditions during the Maha. In some areas where irrigation facilities have been provided cultivation is extended to the second season (Yala). Thus a large extent of the land area is cultivated during the Maha season. On the average 0.52 million hectares of paddy land is cultivated during the Yala (Weeraratne, et al., 1977).

Field data for the Yala season of 1977 was collected at Mahakumbukkadawela in the Puttalam district of the dry zone during months of July to October. Laboratory studies were carried out from October to November. Data for the Maha season of 1977-78 was collected at Amunupitya in the Kurunegala district from February to April, 1978 and laboratory studies were carried out from April to May. The dry zone was selected for this study with the idea that, with the initiation of the Mahaveli Development and Irrigation project, the dry zone offered the greatest potential for future rice production in Sri Lanka.

METHODOLOGY

4.1. Variety and Farm Selection.

Five popular rice varieties, BG. 94-1, BG. 34-8, BG. 11-11, BG. 90-2 and H-4 were selected and studied. The BG. 94-1 and BG. 34-8 varieties were grown during the Yala while the rest were grown during the Maha. The choice of varieties was made within the framework of what farmers preferred to grow during certain seasons. It was difficult to locate farmers within the study area who were growing the same variety during both the Yala and Maha seasons. The choice of varieties studied was, therefore, limited by location and the availability of alternative threshing facilities.

Two farms for each variety were selected on the assumption that the farmers adopted improved production technologies and their management skills and cultural practices were similar. All farms were supplied with irrigation water throughout the cropping seasons.

4.2. Field Measurements for the Yala Season of 1977.

BG. 34-8 and BG. 94-1, high yielding varieties with growth durations of 3 and 3-1/2 months respectively were selected.

One hundred and forty plots, each one square meter in area, were located at random in each farm for data collection. Five additional plots of one square meter each were located at random in each farm for estimating the grain moisture content at each harvest date.

The grain moisture content was measured at four-day intervals, beginning 16 days after 50% heading, with a Satake moisture meter.[4/] The measurements were made at 8.00 a.m. and 2.00 p.m. daily for each variety.

Grain losses were measured on twenty plots at four-day intervals beginning 16 days after 50% heading. The first observations were made on 10 September 1977 on farms growing BG. 94-1 and 21 September on farms growing BG. 34-8, Table 4.1.

4.3. Preharvest.

Preharvest losses were determined by collecting fallen grain within each square meter plot. The empty husks were included as bird damage. Undamaged grain were counted as shattered preharvest grain. The kernels collected along with their moisture content and 1,000 grain weight were converted to kg/ha at 14.5 percent moisture. Empty and split coverings were assumed to be bird damage and were also converted to kg/ha as above.

[4/] 50% emergence of all panicles is referred to as middle heading or 50% heading (Chang and Bardens, 1965).

Table 4.1: Harvesting Schedule for Variety BG. 94-1*

Harvest Date	Days After 50% Heading	Number of Plots
10 Sep.	16	20
14 Sep.	20	20
18 Sep.	24	20
22 Sep.	28	20
26 Sep.	32	20
30 Sep.	36	20
4 Oct.	40	20
	Total Plots	140

*Similar schedules were used for varieties, BG.11-11; BG.34-8, BG.90-2 and H-4.

4.4. Harvesting.

After assessing preharvest shattering losses the plots were harvested, using a traditional sickle, at about 10.00 a.m. on scheduled harvesting dates, Table 4.1. The grain left after the cutting operation, referred to as cutting losses, were collected and converted to kg/ha as before.

4.5. Field Handling.

The harvested stalks from the square meter plots were laid on polythene sheets to assess the losses due to laying and bundling. The stalks were allowed to dry overnight, as is customarily done, loosely bundled with a rope and collected at 11.00 a.m. the following day. The grain fallen on the sheet were counted as laying and bundling losses and converted to kg/ha.

4.6. Transporting.

Fifteen bundles, each containing stalk from a square meter plot, were transported to the common threshing floor approximately 300 meters from the collection site. These bundles were loosely wrapped with polythene sheets to collect the falling grain and carried on the head as is traditional. The shattered grain was collected and the distance from each site to the threshing floor was measured. The collected grain was converted to kg/ha and counted as transport losses.

4.7. Threshing.

The fifteen bundles were subdivided randomly into three 5-bundle samples and used for the following threshing methods: a) buffalo, b) tractor, and c) machine. A pair of buffalos were used to thresh the grain on a mud caked floor. A 35 h.p. tractor was used on a floor covered with a large jute sheet to collect the threshed grain. The third sample was threshed with an Iseki mechanical thresher. A pedal thresher was used to thresh the remaining five bundles on the field. Estimated grain losses included unthreshed grain, wind losses and drum losses. All threshing operations were timed.

4.8. Field Measurements for the Maha of 1977-78.

The Maha season extended from October 1977 to March 1978. The study was made on BG. 90-2, BG. 11-11 and H-4, all improved varieties having growth durations of 4 to 4-1/2 months. Similar collection procedures were used as for the Yala, while the first observations were made on 9 March for H-4, 10 March for BG. 11-11 and 12 March for farms growing BG. 90-2.

4.9. Statistical Analysis.

The data collected for the two seasons and five varieties were analyzed using linear and polynomial regression techniques. The statistical package "Shazam" was used for the analysis (See Appendix A1). Harvest date beyond 50% heading was used as an independent variable against bird and rodent damage, preharvest losses, postharvest losses, transport losses, and broken grains for the four threshing methods; all assumed to be dependent on the harvest dates. A polynomial regression was performed using the grain moisture content as a dependable variable against the independent harvest date variable. The resulting predictive equations were used in simulating the in-field post production subsystem described in Chapter V. Characteristics of the five varieties under test as reported by the Rice Breeding Research Station at Batalagoda in Sri Lanka are given in Table 4.2.

Table 4.2. Characteristics of the Selected Varieties

Variety	Growth Duration (months)	Panicle length cm	Panicle weight g	Panicle No. of grains	1000 grain wt.	Shattering %	Head Rice / Broken Rice %
BG.11-11	4-4½	23.5	2.9	187	16.66	17.8	53.9/19.9
BG.94-1	3½	24.2	---*	---	23.35	---	---
BG.90-2	4-4½	28.4	---	---	27.83	---	63.6/10.3
BG.34-8	3	24.6	4.2	172	25.9	---	63.4/6.6
H_4	4-4½	28.9	3.0	210	29.1	0.63	68.6/4.2

*not available

Source: Batalagoda Rice Research Station, Sri Lanka.

RESULTS

4.10. Lodging.

Lodging characteristics of all varieties were studied throughout the data collection period. Although a quantitative survey was not made, the fields were observed for lodging, beginning at 50% heading.

BG. 34-8 was found to lodge about 25 days after 50% heading. However, lodging of BG. 34-8 fields were not uniform resulting in areas of lodged stalks amongst standing stalks up to 40 days beyond 50% heading. Lodging in these fields may have been due to the influence of climatic factors such as rain and wind. Excessive grain damage was observed on lodged plants in water-logged fields.

BG. 11-11 had a higher resistance to lodging in the observed fields, but at maturity (about 28 days after 50% heading) and beyond, climatic factors caused a majority of the plants to lodge. Complete lodging was observed in fields where farmers delayed harvesting beyond 40 days after 50% heading. Grain spoilage resulting from lodged stalk in standing water was low, since lodged BG. 11-11 plants were not exposed to monsoonal rains that result in logged fields.

H-4 lodged at heading or immediately thereafter. As a varietal characteristic, H-4 responds to heavy nitrogen fertilizer application and has tall stems which makes it susceptible to lodging. Fields under observation had plants that were completely lodged at the inception of data collection. Areas of excessive rodent damage were observed in many of the fields. The lodged plants provided a perfect cover for the common field mouse which feeds on mature grains of the fallen panicles. The fields under observation were not exposed to monsoonal rain showers and grain spoilage due to water logging was not observed. Monsoonal rains resulting in water-logged fields would have submerged the entire crop leading to high grain spoilage.

Lodging was not observed in fields cultivated with BG. 94-1 and BG. 90-2. These varieties exhibited a resistance to lodging even beyond full maturity of grains and stems. Shorter and thicker stems of these two varieties increased their resistance to lodging in spite of their high response to nitrogen fertilizer.

4.11. Grain Moisture Content.

Grain moisture was observed on all varieties at 8.00 a.m. and 2.00 p.m. on scheduled harvest dates. Table 4.3. illustrates the variation in moisture content at 8.00 a.m. and 2.00 p.m. on scheduled harvest dates for varieties BG. 34-8, BG. 11-11, BG. 90-2 and H-4 respectively. The difference in moisture contents measured at 8.00 a.m. and 2.00 p.m. varied with varieties and was influenced by environmental conditions.

The moisture content of the rice grain decreased as the plant reached physiological maturity, (Wanders, 1974).

Table 4.3. Grain Moisture of Varieties Under Test

Variety	Days After Heading													
	16		20		24		28		32		36		40	
	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00	8:00	2:00
H_4 Farm 1	---	---	26.00	26.00	24.16	19.06	22.70	20.33	23.10	20.20	26.00	20.16	21.35	17.87
H_4 Farm 2	---	---	26.00	26.00	23.95	20.13	22.55	19.98	24.35	19.76	26.00	19.10	21.06	17.74
BG.94-1 (1)	26.00	26.00	25.00	22.60	21.80	19.24	21.10	18.58	20.60	16.76	18.80	17.02	26.00	15.30
BG.94-1 (2)	26.00	26.00	25.40	21.56	21.80	19.84	20.6	18.36	20.9	16.86	18.80	16.48	25.68	14.60
BG.11-11 (1)	26.00	23.17	25.13	18.87	24.33	21.72	25.50	22.20	25.10	20.10	22.50	19.18	21.90	13.84
BG.11-11 (2)	26.00	23.00	24.80	20.80	24.30	20.15	24.28	21.45	24.94	19.55	20.84	18.46	19.74	15.03
BG.34-8 (1)	25.20	24.20	24.10	16.32	25.40	16.04	21.02	15.74	18.22	14.70	17.92	13.94	---	---
BG.34-8 (2)	25.70	24.70	24.90	16.76	25.20	16.20	18.50	14.12	16.23	13.80	18.40	14.10	---	---
BG.90-2 (1)	25.00	22.40	25.50	24.30	24.16	14.32	25.96	23.70	22.63	21.84	22.40	15.76	20.46	14.60
BG.90-2 (2)	25.70	23.18	24.80	22.46	22.96	20.00	25.16	20.80	22.05	19.65	21.40	16.38	20.31	14.72

Moisture loss increased during the daytime when climatic conditions cause an increased evaporation loss of moisture to the environment. Cooling of the air at night accompanied by an increase in the relative humidity caused moisture to be readsorbed resulting in a higher grain moisture content during the early daytime hours. Similar cyclic absorption and desorption properties of the rice grain from drying during daylight hours to rewetting at night were observed by Grist (1975); Smith and Macrea Jr. (1951) and Curfs (1974).

Polynomial regression analysis of the average daily moisture content for different harvest dates resulted in the formulation of prediction equations for the five rice varieties.

<u>BG. 34-8</u>

The field data was fitted to a second order polynomial regression line (equation 4.1), using GAV, the average grain moisture content as the dependent variable against the independent harvest date variable, N.

$$Y=a_0+a_1X+a_2X^2 \qquad (4.1)$$

The resulting prediction equation (4.2),

$$GAV=42.491-1.4136*N+0.18666*10^{-1}*N^2 \qquad (4.2)$$

had a r^2 value=0.9109 indicating that 91 percent of the variation in GAV was explained by the regression on the harvest date variable. The regression coefficients a_1 and a_2 were both significant at the 0.05 probability level.

BG. 11-11

Equation (4.3),

$$GAV=18.710+0.51263*N-0.13181*10^{-1}*N^2 \qquad (4.3)$$

had a r^2 of 0.8247. Regression coefficients a_1 and a_2 were both significant at the 0.05 probability level.

BG. 90-2

A prediction equation for variety BG. 90-2 is seen in equation (4.4) and was given as,

$$GAV=21.328+0.32307*N-0.10461*10^{-1}*N^2 \qquad (4.4)$$

where r^2=0.6971, indicating that 69 percent of the variation in GAV was explained by variable N (harvest dates). Regression coefficients a_1 and a_2 were not significant at 0.05, but were significant at 0.5 and 0.3 levels respectively. The fluctuations in grain moisture at various stages of maturity, influenced by the climatic conditions, such as rain and relative humidity, may have resulted in scattered data points, lowering the r^2 and providing a lower level of probability for its regression coefficients. The overall equation was, however significant at F (α=0.01).

H-4

The predictive equation for GAV was given in equation (4.5) as,

$$GAV=37.924-0.87339*N+0.11099*10^{-1}*N^2 \qquad (4.5)$$

and had an r^2 value of 0.5704. The coefficients a_1 and a_2

were not significant at $t(\alpha=0.05)$, but were significant at the 0.3 and 0.4 levels respectively. The overall equation, however, was significant at $F(\alpha=0.025)$.

BG. 94-1

The predictive equation for GAV was given as,

$$GAV=46.982-1.7116*N+0.26031*10^{-1}*N^2 \qquad (4.6)$$

and had a r^2 of 0.9561. The coefficients a_1 and a_2 were significant at $t(\alpha=0.01)$.

The variation in average grain moisture content with the harvest dates as well as their respective regression equations are illustrated in Figure 4.1.

4.12. Sunchecked Grain.

The percentage of sunchecked grains was calculated on five samples having 10 grains each, on every harvest date beyond 50% heading. The husks of each grain was removed and examined for sunchecks. A complete fissure along the width of the grain was taken as evidence of sunchecking. The number of sunchecked grains in each sample was used to calculate the percentage of sunchecks.

The incidence of sunchecking was seen to increase with the maturity of the grain and rice plant. The results were similar to those observed by Wanders (1974), Grist (1975), Langfield (1957), Smith and Macrea Jr. (1951) and Coyard (1950).

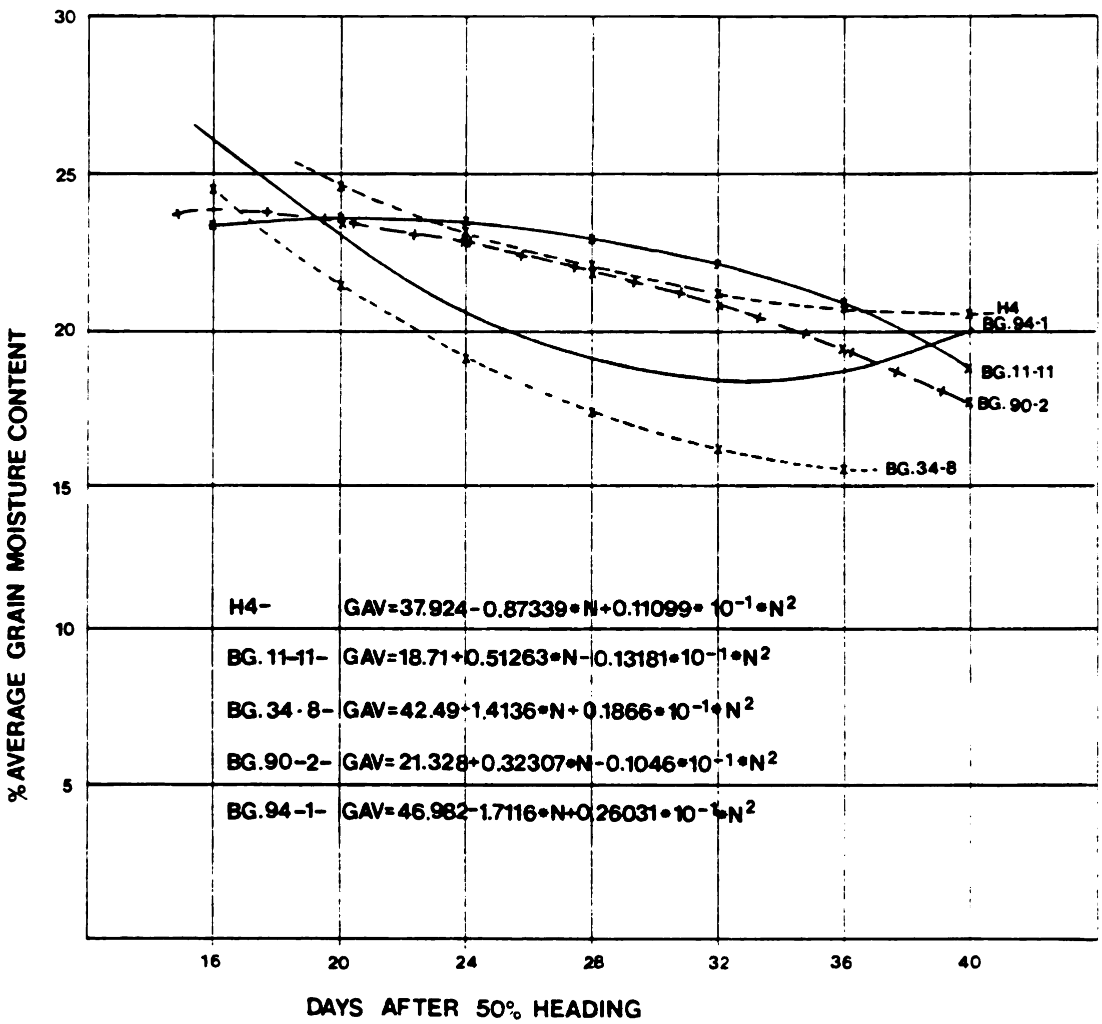


Figure 4.1 Variations in Average Grain Moisture Contents with Harvest Dates

Linear regression analysis techniques were used to generate predictive equations to fit the observed field data. Percentage sunchecks (SNC), the dependent variable was used against the independent harvest date variable, (N). Equation (4.7) represents the model of the predictive equation,

$$Y=a+bX \qquad (4.7)$$

where Y= the predicted percentage of sunchecks, SNC

X= the harvest date, N.

b= the regression coefficient and slope of the equation

a= a constant of regression and the intercept of the equation (4.7).

BG. 34-8

The predictive equation for variety BG. 34-8 was given in equation (4.8) as,

$$SNC=-35.467+2.3*N \qquad (4.8)$$

and had a r^2 value of 0.8419 and a regression coefficient b, significant at $t(\alpha=.01)$.

BG. 11-11

Equation (4.9),

$$SNC=-27.357+3.1607*N \qquad (4.9)$$

is the predictive equation for BG. 11-11 and had an r^2 value of 0.9326 explaining that 93 percent of the variation in SNC was influenced by the independent harvest date variable, (N). The regression coefficient b was significant at $t(\alpha=0.01)$.

BG. 90-2

The prediction equation for percentage of sunchecked grains for different harvest dates N, for variety BG. 90-2 was given as,

$$SNC=-31.214+2.2679*N \tag{4.10}$$

and had a r^2 value of 0.8975 and a regression coefficient b, significant at $t(\alpha=0.01)$.

H-4

The equation (4.11) illustrated the variation of SNC with N for variety H-4.

$$SNC=-73.857+3.3786*N \tag{4.11}$$

had a r^2 value of 0.8936 and a regression coefficient significant at $t(\alpha=0.01)$.

BG. 94-1

The predictive equation for SNC was given as,

$$SNC=-18.750+1.3482*N \tag{4.12}$$

and had a r^2 of 0.9018, with its coefficient significant at $t(\alpha=0.01)$.

The variations in the percentage of sunchecked grain with the different harvest dates beyond 50% heading are illustrated by the prediction curves in Figure 4.2.

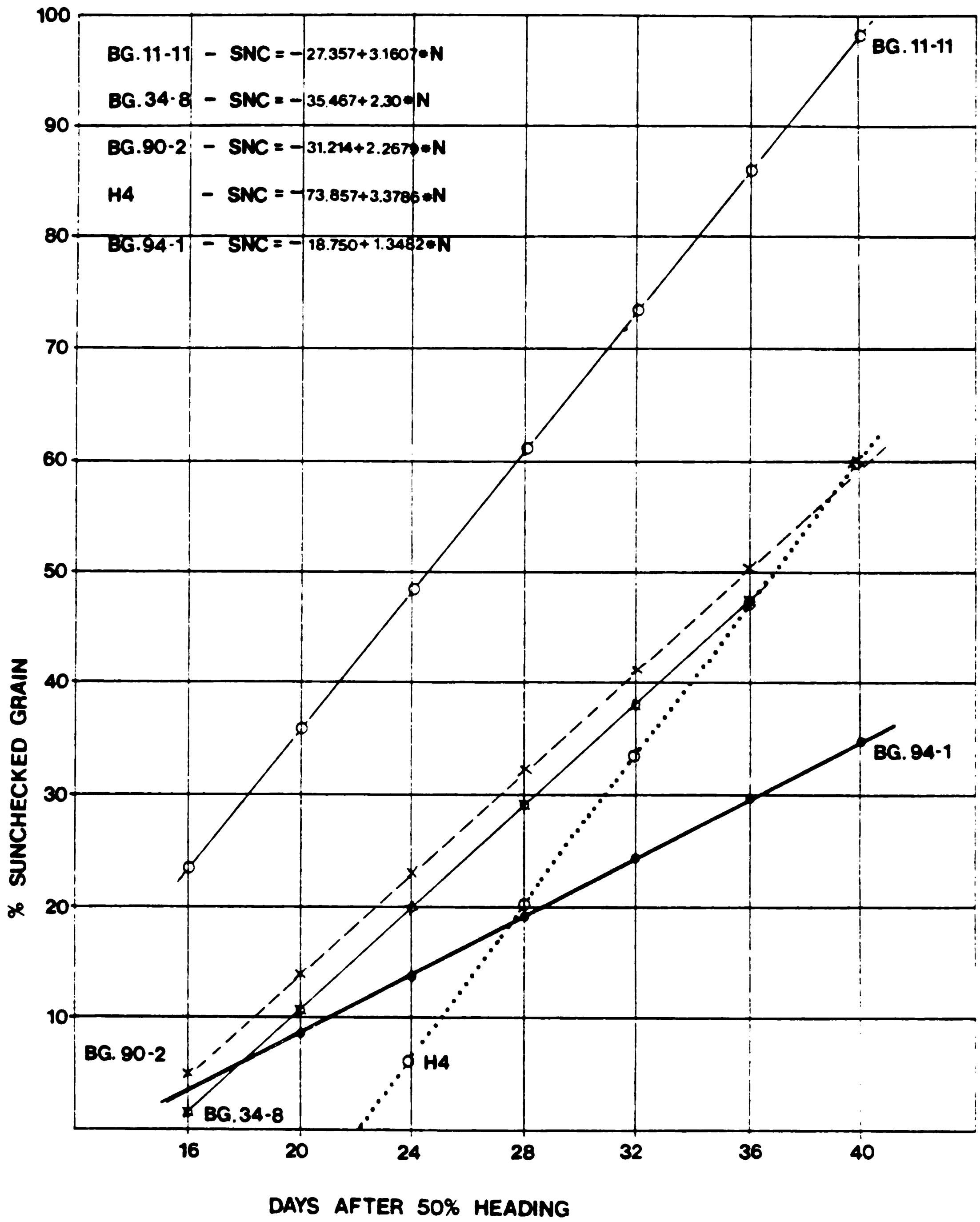


Figure 4.2 Variation in Sunchecked Grain at Different Harvest Dates

4.13. Losses Before Cutting.

Regression equations were fitted to field data collected before the cutting operation. Losses before cutting were used as the dependent variable against the independent harvest date variable. Equation (4.13) represents the model of the prediction equation,

$$Y=a+bX \qquad (4.13)$$

where X= the independent harvest date, N.

Y= the predicted loss before cutting, PHV. (kg/ha)

b= the regression coefficient and slope of the equation

a= the constant of regression and the intercept of the equation (4.13).

BG. 34-8

Equation (4.14) illustrates the predictive equation fitted to the field data for variety BG. 34-8.

$$PHV=-7.6111+1.0204*N \qquad (4.14)$$

had a r^2 value of 0.7753 with a significance at $t(\alpha=0.01)$ for the regression coefficient b.

BG. 11-11

Equation (4.15),

$$PHV=-4.3123+0.66924*N \qquad (4.15)$$

represents the prediction equation of losses before cutting for variety BG. 11-11 and had a r^2 value of 0.9043. The regression coefficient b was significant at $t(\alpha=0.01)$.

BG. 90-2

Equation (4.16) representing the cutting losses for BG. 90-2 was given as,

$$PHV=-1.7188+0.34585*N \qquad (4.16)$$

and had a r^2 value of 0.9476 and its regression coefficient b was significant at $t(\alpha=0.01)$.

H-4

Equation (4.17) given as,

$$PHV=-6.5126+0.45614*N \qquad (4.17)$$

is a predictor of losses for variety H-4 and had a r^2 value of 0.9067. The regression coefficient b, was significant at $t(\alpha=0.01)$.

BG. 94-1

The prediction equation for BG. 94-1 was given as,

$$PHV=-2.4723+0.41835*N \qquad (4.18)$$

and had a r^2=0.6641, with its regression coefficient significant at $t(\alpha=0.01)$.

Regression curves for losses before cutting varying with the harvest date beyond the 50% heading stage are illustrated in Figure 4.3.

4.14. Losses at Cutting.

Predictive equations were obtained by using linear regression techniques on the observed field data. Losses at

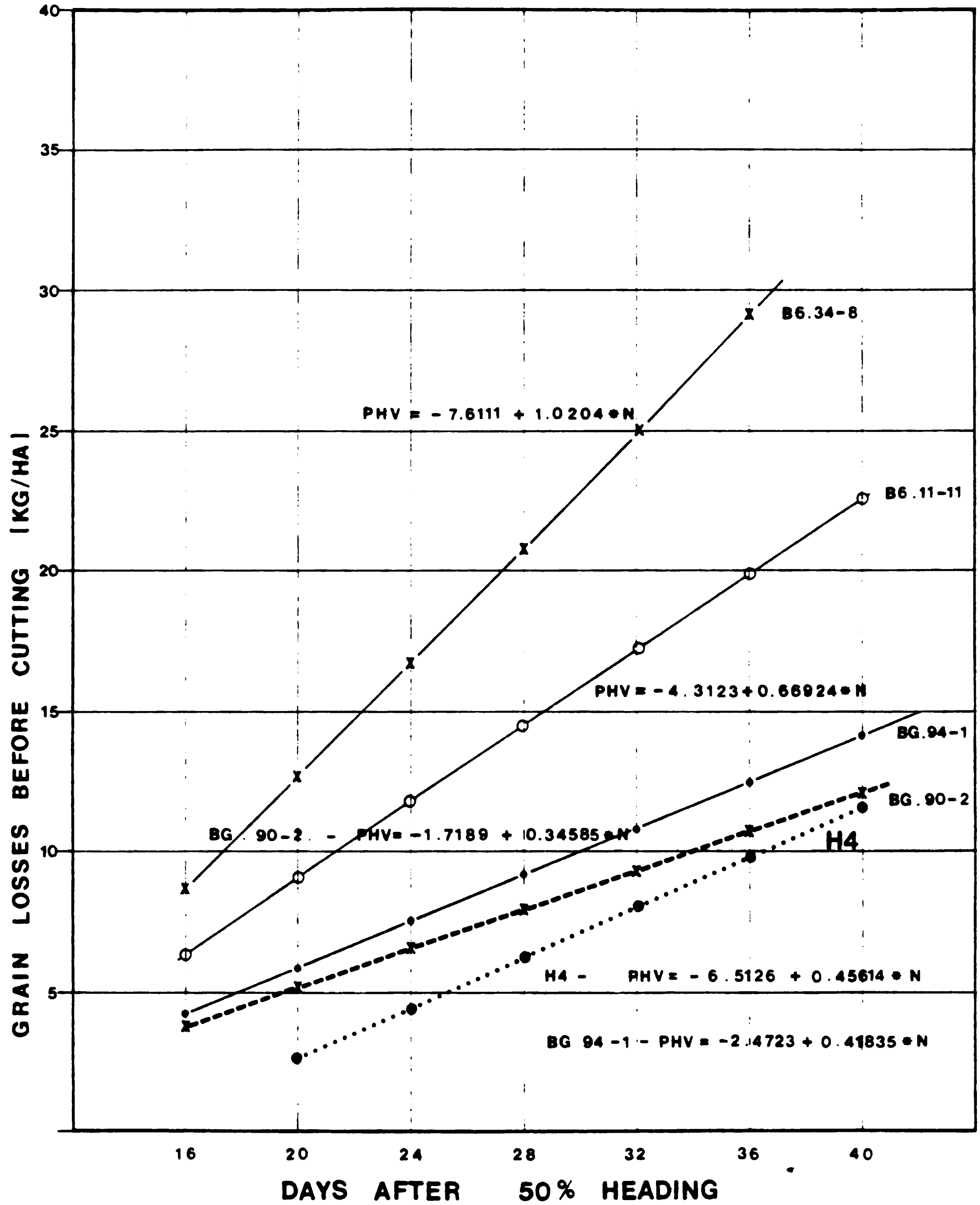


Figure 4.3 Losses Before Cutting as Influenced by Harvest Dates

cutting were used as a dependent variable against the independent harvest date variable. The data was fitted according to a linear model, equation (4.19).

$$Y=a+bX \qquad (4.19)$$

where X= the independent harvest date variable, N.

Y= the predicted value for losses at cutting PSV (kg/ha).

b= the regression coefficient or slope of the equation

a= the constant of regression or the intercept of the equation (4.19).

<u>BG. 34-8</u>

Equation (4.20) is a predictor of PSV for the variety BG. 34-8 and was given by,

$$PSV=-10.810+1.1964*N \qquad (4.20)$$

where $r^2=0.7873$ and the regression coefficient b was significant at $t(\alpha=0.01)$.

<u>BG. 11-11</u>

Equation (4.21),

$$PSV=-16.342+1.4822*N \qquad (4.21)$$

is the predictor of PSV for variety BG. 11-11 and had a r^2 value of 0.8058 and a regression coefficient b significant at $t(\alpha=0.01)$.

<u>BG. 90-2</u>

$$PSV=-16.085+1.0388*N \qquad (4.22)$$

is the predictive equation of losses at cutting for variety

BG. 90-2, and had a r^2 value of 0.9660 which indicated a high correlation between the variation of PSV with the independent variable, N. The regression coefficient b was significant at $t(\alpha=0.01)$.

H-4

Equation (4.23) represents the predictor of losses in variety H-4 for different harvest dates, N.

$$PSV=-11.629+0.69289*N \tag{4.23}$$

had an r^2 value of 0.8919 and a regression coefficient significant at $t(\alpha=0.01)$.

BG. 94-1

The prediction equation was given as,

$$PSV=-27.304+1.6658*N \tag{4.24}$$

having a r^2 of 0.8103, its regression coefficient significant at $t(\alpha=0.02)$.

Regression curves representing the variations in cutting losses with harvest dates are illustrated in Figure 4.4.

4.15. Bundling Losses.

Data collected for grain losses at the time of bundling were used to fit regression equations for the different varieties under study. Bundling losses, BNDL, were used as the dependent variable against the independent harvest date

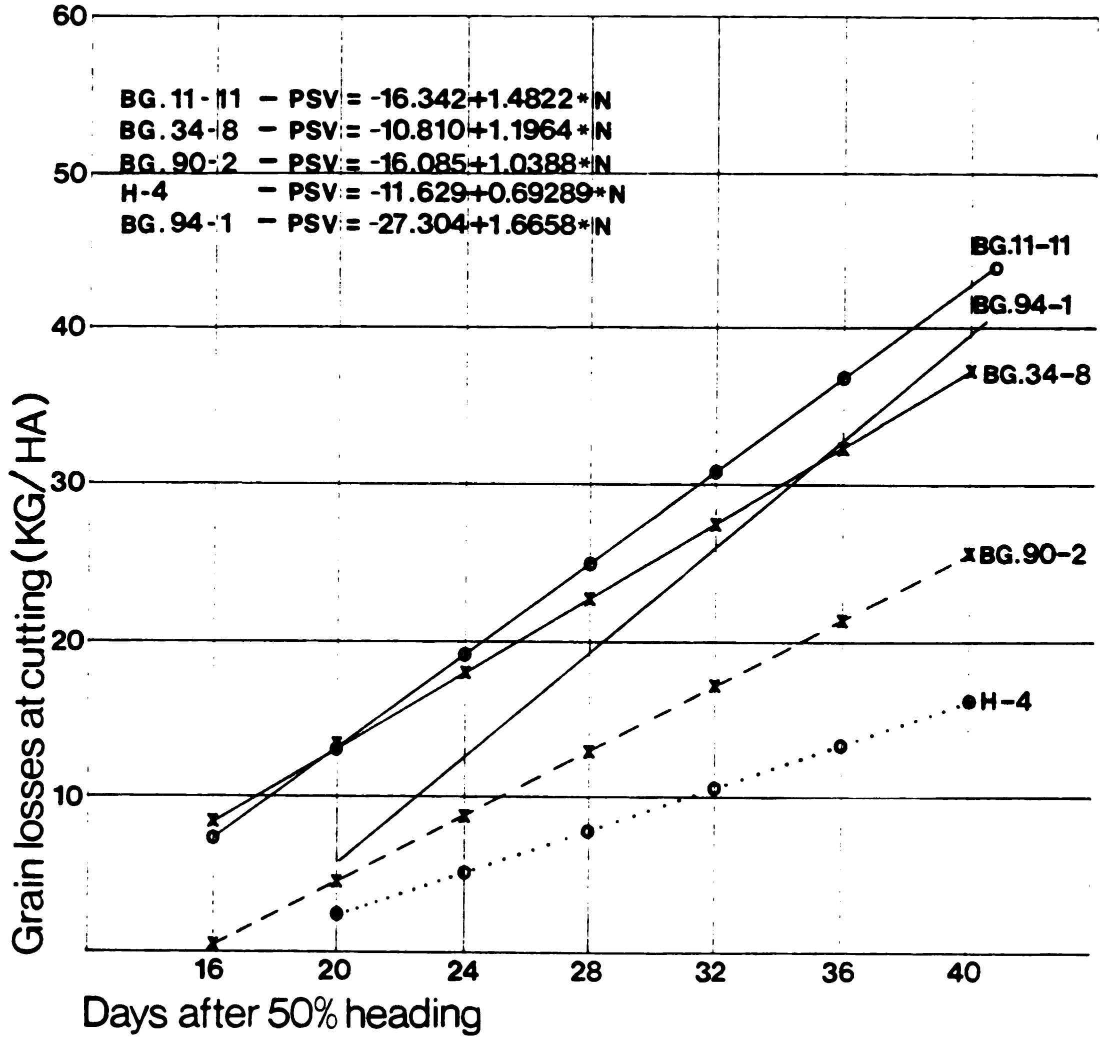


Figure 4.4 Losses at Cutting as Influenced by Harvest Dates

variable, N. Equation (4.25) was the model of the linear equation used in the regression analysis of the field data.

$$Y=a+bX \tag{4.25}$$

where X= the independent variable for harvest date, N.

Y= the predicted values for the dependent bundling losses, BNDL (kg/ha).

b= the regression coefficient or slope of the equation

a= the regression constant or intercept of equation (4.25).

BG. 34-8

Equation (4.26), the predictor of losses for variety BG. 34-8 was given by,

$$BNDL=-20.531+1.4560*N \tag{4.26}$$

where r^2=0.7042 and b the regression coefficient was significant at $t(\alpha=0.01)$.

BG. 11-11

Equation (4.27),

$$BNDL=-13.189+1.1246*N \tag{4.27}$$

was the regression equation to predict the bundling losses for variety BG. 11-11. The r^2 value was 0.9294 and the coefficient b was significant at $t(\alpha=0.01)$.

BG. 90-2

Equation (4.28) predicts the losses at bundling for variety BG. 90-2 and was given as,

$$BNDL=-3.3327+0.43629*N \tag{4.28}$$

and had a r^2 value of 0.9746 with the regression coefficient b, significant at $t(\alpha=0.01.)$.

H-4

Equation (4.29),

$$BNDL=-5.4452+0.44429*N \qquad (4.29)$$

had a r^2 value of 0.9106 and had a regression coefficient significant at $t(\alpha=0.01)$.

BG. 94-1

The prediction equation was given as,

$$BNDL=1.2041+0.30353*N \qquad (4.30)$$

having a r^2 of 0.3852 with its regression coefficient significant at $t(\alpha=0.02)$.

Regression curves fitted to the collected data are illustrated in Figure 4.5.

4.16. Grain Losses at Transport.

Grain losses at transport, collected for the different varieties under study, were used to fit linear regression equations. Grain losses at transport, TRL in kg/ha were used as a dependent variable against the independent harvest date variable. The equations were fitted to the model represented by equation (4.31)

$$Y=a+bX \qquad (4.31)$$

where X= the independent harvest date variable, N.

Y= the predicted value of transport losses TRL in (kg/ha).

b= the regression coefficient and slope of the equation

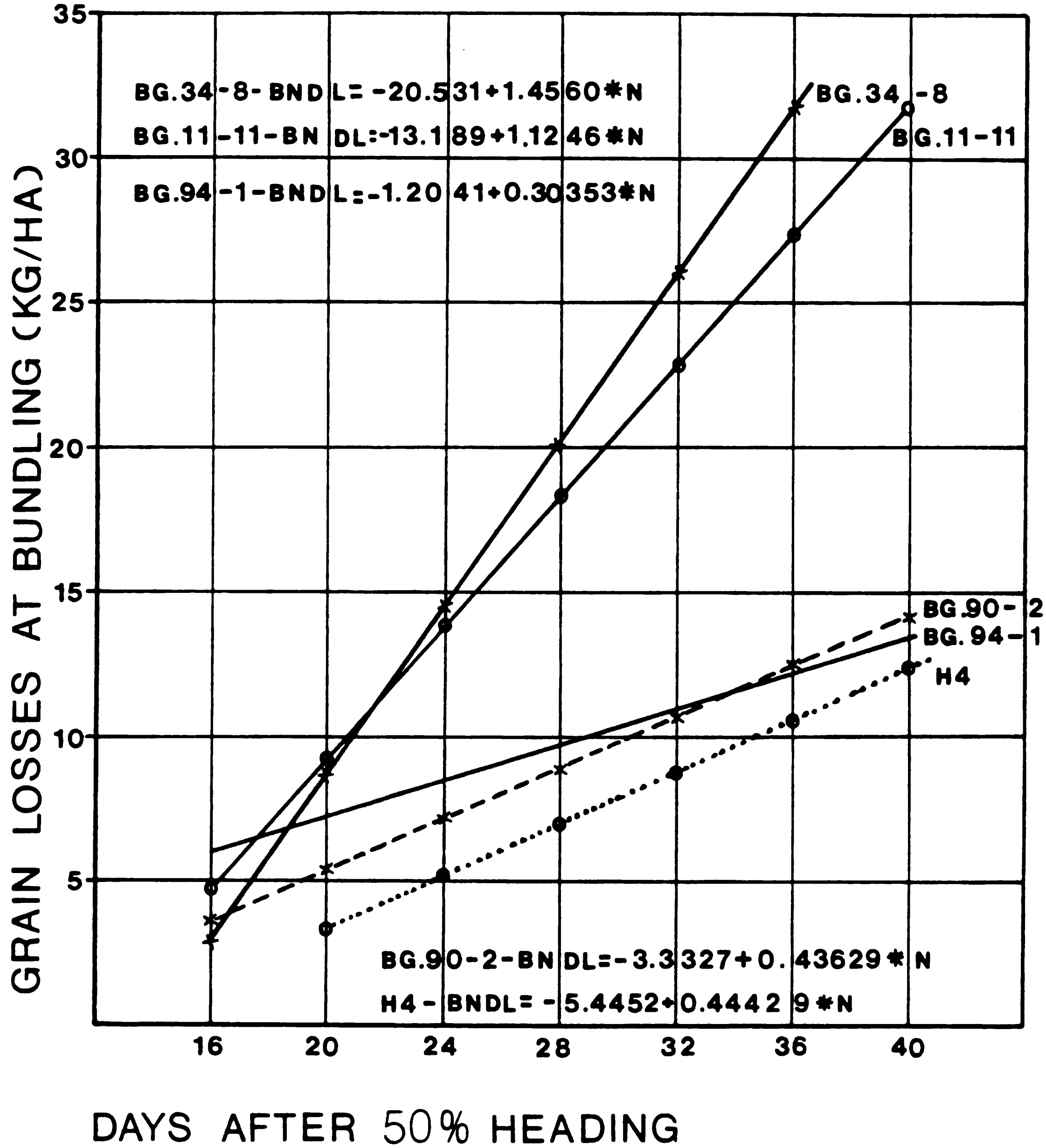


Figure 4.5 Bundling Losses as Influenced by Harvest Dates

a= the regression constant and intercept of equation (4.31).

BG. 34-8

Equation (4.32) represents the predictive equation of grain losses at transport for variety BG. 34-8.

$$TRL=6.2848+110857*N \tag{4.32}$$

had a r^2 value of 0.2539 and its coefficient b, however, was significant at $t(\alpha=0.05)$. The low r^2 value in this instance may be due to the high loss count on farm A on the first harvest date, 16 days after 50% heading. Grain losses collected on the first harvest date were 57.2 kg/ha and higher than that of the second harvest date having losses of 19.6 kg/ha. The losses on the first harvest date were almost equal to the losses (57.8 kg/ha) on the last harvest date 36 days after 50% heading. An error in the data collection of the first harvest date may be a reason for the initially high loss count and low r^2 value.

BG. 11-11

The prediction equation of grain losses for BG. 11-11 was given as,

$$TRL=-23.206+2.4139*N \tag{4.33}$$

and had an r^2 value of 0.9251 with its regression coefficient b being significant at $t(\alpha=0.01)$.

BG. 90-2

Equation (4.34) represents the predictor for BG. 90-2, and was given as,

$$TRL=-0.94286X10^{-1}+1.0127*N \tag{4.34}$$

and had a r^2 value of 0.8784 with a regression coefficient b significant at $t(\alpha=0.01)$.

H-4

The prediction equation for H-4 is given as,

$$TRL=-10.581+1.0622*N \tag{4.35}$$

Equation (4.35) had a r^2 value of 0.9109 with a regression coefficient b significant at $t(\alpha=0.01)$.

BG. 94-1

The prediction equation for grain losses at transport was given as,

$$TRL=12.249+1.0545*N \tag{4.36}$$

where $r^2=0.5643$ and the regression coefficient was significant at $t(\alpha=0.01)$.

Prediction equations for transport losses varying with harvest dates are illustrated in Figure 4.6.

4.17. Bird and Rodent Losses.

Grain losses due to birds and rodents were used as a dependent variable against the independent harvest date variable. Regression equations were fitted to the collected data, following the model of equation (4.37).

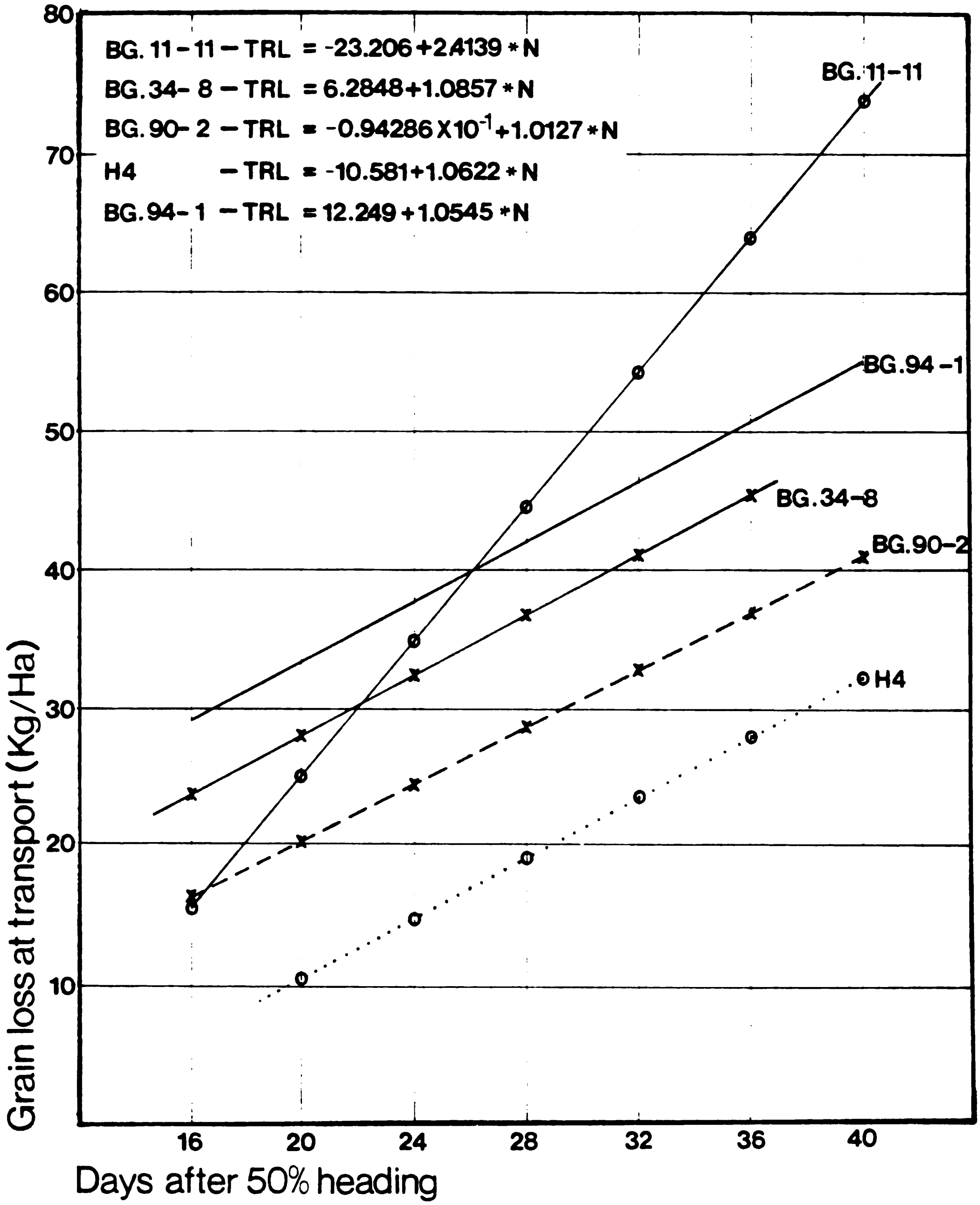


Figure 4.6 Transport Losses as Influenced by Harvest Dates

$$Y=a+bX \tag{4.37}$$

where X= the independent harvest date variable, N.

Y= the predicted grain losses BRD in kg/ha

b= the regression coefficient and slope of the equation

a= the regression constant and intercept of equation (4.37).

BG. 34-8

Equation (4.38),

$$BRD=-2.1266+0.53061*N \tag{4.38}$$

represents the predictive equation for variety BG. 34-8 and had a r^2 value of 0.8051 with the regression coefficient b being significant $t(\alpha=0.01)$.

BG. 11-11

The prediction equation for grain losses due to birds and rodents for variety BG. 11-11 was given as,

$$BRD=-37.559+2.5402*N \tag{4.39}$$

and had a r^2 value of 0.7950 with the regression coefficient b significant at $t(\alpha=0.01)$.

BG. 90-2

Equation (4.40), the predictive equation for BG. 90-2 was given by,

$$BRD=-9.5541+1.0324*N \tag{4.40}$$

where r^2=0.8486 and the regression coefficient b was significant at $t(\alpha=0.01)$.

H-4

$$BRD=-15.289+1.3936*N \tag{4.41}$$

was the predictive equation for variety H-4 and had r^2=0.7853 with the regression coefficient significant at $t(\alpha=0.01)$.

BG. 94.1

The prediction equation was given as,

$$BRD=-59.758+3.1338*N \tag{4.42}$$

and had a r^2 value of 0.7577 with its regression coefficient significant at $t(\alpha=0.01)$.

The curves of the predictive equations representing the variations in BRD to the independent harvest date variable N, are illustrated in Figure 4.7.

4.18. Percentage of Broken Grains.

The percentage of broken grains at milling for the different rice varieties threshed by four threshing methods was used as the dependent variable against the independent harvest date variable. Second order polynomial regression equations were used to fit the data obtained. Equation (4.43) represents the model used to fit the predictive equations to the collected data.

$$Y=a_0+a_1X+a_2X^2 \tag{4.43}$$

where X= the independent harvest date variable, N.

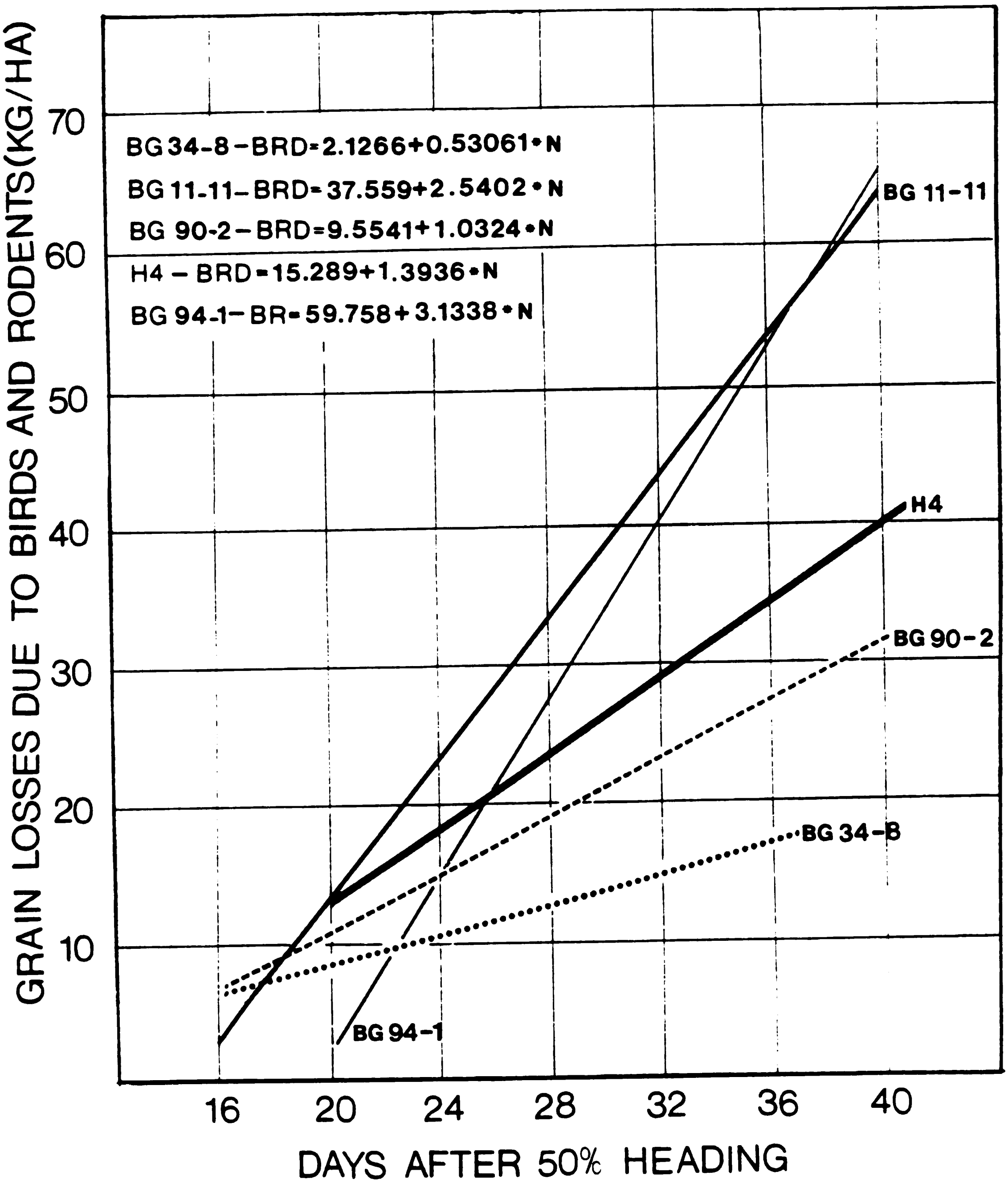


Figure 4.7 Bird and Rodent Losses as Influenced by Harvest Dates

y= the predicted percentage of broken grains, BK1, BK2, BK3 and BK4.
BK1= Pedal threshing
BK2= Buffalo threshing
BK3= Tractor threshing
BK4= Mechanical threshing

a_1= regression coefficient for X

a_2= regression coefficient for X^2

a_0= the regression constant.

BG. 34-8

Equation (4.44) represents the percentage broken grains at milling using a pedal drum for threshing.

$$BK1=25.832-1.8239*N+0.36239X10^{-1}*N^2 \quad (4.44)$$

had a r^2=0.9750 and its regression coefficients a_1 and a_2 were significant at t(α =0.01)

Equation (4.45) represents the percentage broken grain using buffalos for threshing.

$$BK2=81.220-5.0122*N+0.88493*10^{-1}*N^2 \quad (4.45)$$

had a r^2=0.8343 and its coefficient $a_1$and a_2 were significant at t(α =0.05).

Equation (4.46) for predicting the broken grain using a tractor to thresh the paddy was given as,

$$BK3=56.368-2.6417*N+0.45748*10^{-1}*N^2 \quad (4.46)$$

and had a r^2=0.3803 with a_1 and a_2 being significant at t(α=0.4 and t(α =0.5).

$$BK4=105.94-7.4932*N=0.1440*N^2 \quad (4.47)$$

represents the predictive equation of the percentage broken grains using a machine for threshing. Equation (4.47) had a r^2 value of 0.9447 and its regression coefficients a_1 and a_2 were significant at $t(\alpha=0.01)$.

Regression equations for variety BG.34-8 representing the percentage of broken grains using different threshing methods are illustrated in Figure 4.8.

<u>BG. 11-11</u>

Equation (4.48) represents the predictor for percentage broken grains using the pedal thresher on variety BG. 11-11.

$$BK1=58.972-2.9741*N+0.5465*10^{-1}*N^2 \qquad (4.48)$$

and had a r^2 value of 0.9107 with its regression coefficients a_1 and a_2 significant at $t(\alpha=0.01)$.

Equation (4.49) predicts the percentage broken grains at different harvest dates using buffalos as a means of threshing.

$$BK2=77.180-3.3617*N+0.59658*10^{-1}*N^2 \qquad (4.49)$$

had a r^2 value of 0.8849 and its regression coefficients were significant at $t(\alpha=0.01)$.

Equation (4.50) predicts the percentage of broken grains using the tractor as a means of threshing.

$$BK3=82.025-3.7745*N+0.68036*10^{-1}*N^2 \qquad (4.50)$$

had a r^2 value of 0.8416 and its regression coefficients were significant at $t(\alpha=0.01)$.

Equation (4.51) predicts the percentage of the broken grains for mechanical threshing.

$$BK4=66.581-3.2590*N+0.59315*10^{-1}*N^2 \qquad (4.51)$$

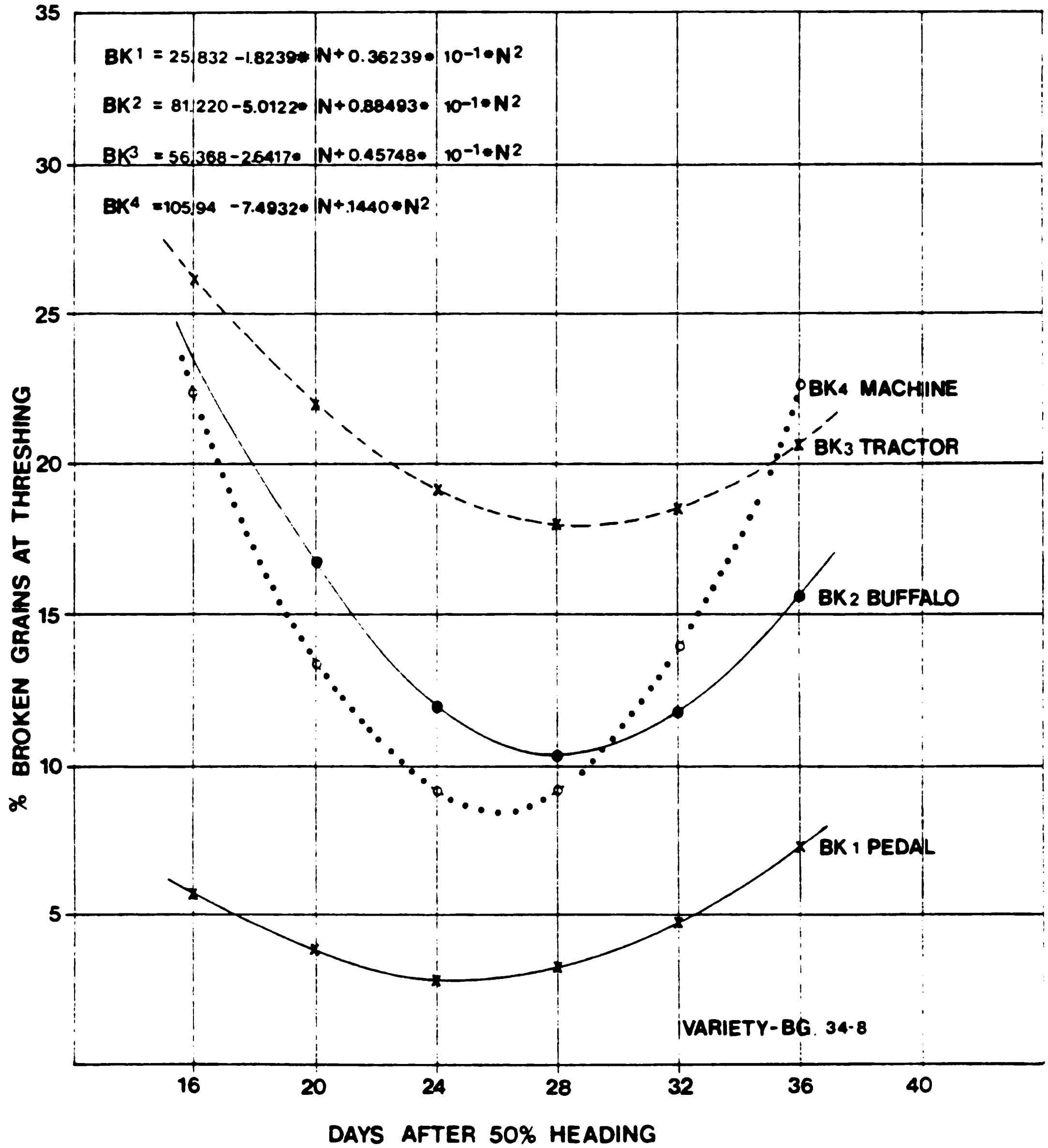


Figure 4.8 Percentage Broken Grains at Threshing - Variety BG. 34-8

had a r^2 value of 0.8404 and its regression coefficients a_1 and a_2 were significant at $t(\alpha=0.01)$.

Figure 4.9 illustrates the regression curves obtained for the four threshing methods.

BG. 90-2

Equation (4.52) predicts the percentage broken grains of rice using the pedal thresher on BG. 90-2 at different harvest dates.

$$BK1=37.715-2.0282*N+0.35848*10^{-1}*N^2 \quad (4.52)$$

had a r^2 value of 0.7743 and its regression coefficient a_1 and a_2 were significant at $t(\alpha=0.025)$.

Equation (4.53), the predictor of broken grains using buffalos as a means of threshing was given as

$$BK2=53.399-2.3001*N+0.40997*10^{-1}*N^2 \quad (4.53)$$

and had a $r^2=0.6517$ with its regression coefficients significant at $t(\alpha=0.025)$.

Equation (4.54) predicts the percentage broken grains using a tractor for threshing BG. 90-2.

$$BK3=66.067-3.1068*N+0.53571*10^{-1}*N^2 \quad (4.54)$$

had a r^2 value of 0.8224 with its regression coefficients significant at $t(\alpha=0.01)$.

Equation (4.55) predicts the percentage of broken grains using a mechanical thresher.

$$BK4=38.664-1.4785+0.24874*10^{-1}*N^2 \quad (4.55)$$

had a r^2 value of 0.6841 and its regression coefficients

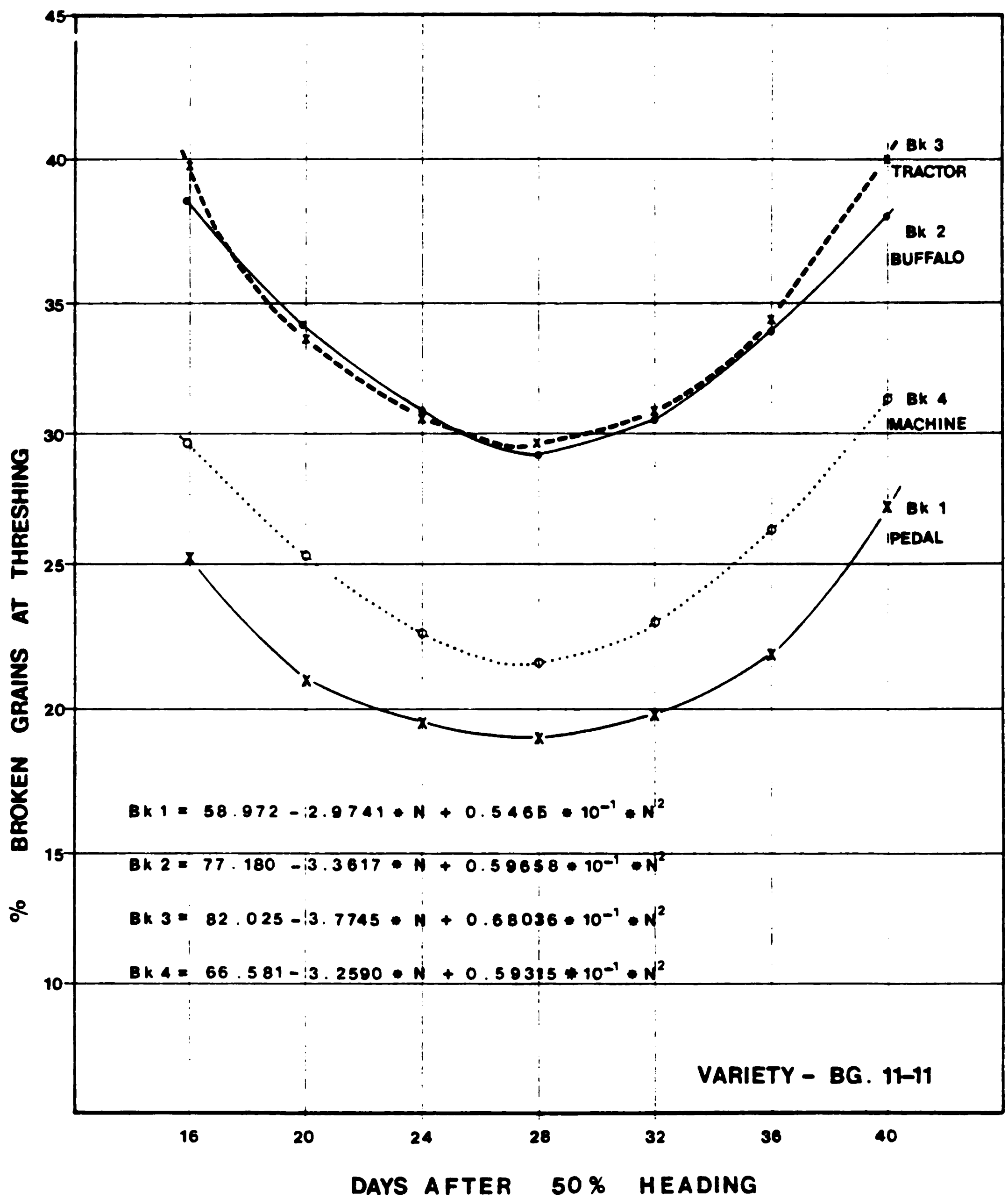


Figure 4.9 Percentage Broken Grains at Threshing - Variety BG. 11-11

were significant at $t(\alpha=0.025)$.

The curves obtained for the four threshing methods are illustrated in Figure 4.10.

H-4

Equation (4.56) is a prediction equation for the percentage of broken grains using a pedal drum for threshing H-4 paddy.

$$BK1=45.343-2.4959*N+0.43426*10^{-1}*N^2 \quad (4.56)$$

had a r^2 value of 0.8712 and its regression coefficient a_1 and a_2 were both significant at $t(\alpha=0.025)$.

Equation (4.57) a predictor of the percentage broken grains using buffalos for threshing was given as,

$$BK2=58.904-2.5852*N+0.48103*10^{-1}*N^2 \quad (4.57)$$

and had a r^2 of 0.8666 with its regression coefficients a_1 and a_2 significant at $t(\alpha=0.025)$.

A prediction of the percentage broken grains using a tractor to thresh H-4 paddy is given by

$$BK3=96.981-5.1712*N+0.90647*10^{-1}*N^2 \quad (4.58)$$

Equation (4.58) had a r^2 value of 0.9747 with its regression coefficients a_1 and a_2 significant at $t(\alpha 0.01)$.

Equation (4.59) is a prediction equation for the percentage of broken grains using a machine for threshing.

$$BK4=40.547-2.058*N+0.37232*10^{-1}*N^2 \quad (4.59)$$

had a r^2 value of 0.9974 with its regression coefficients a_1 and a_2 significant at $t(\alpha=0.01)$.

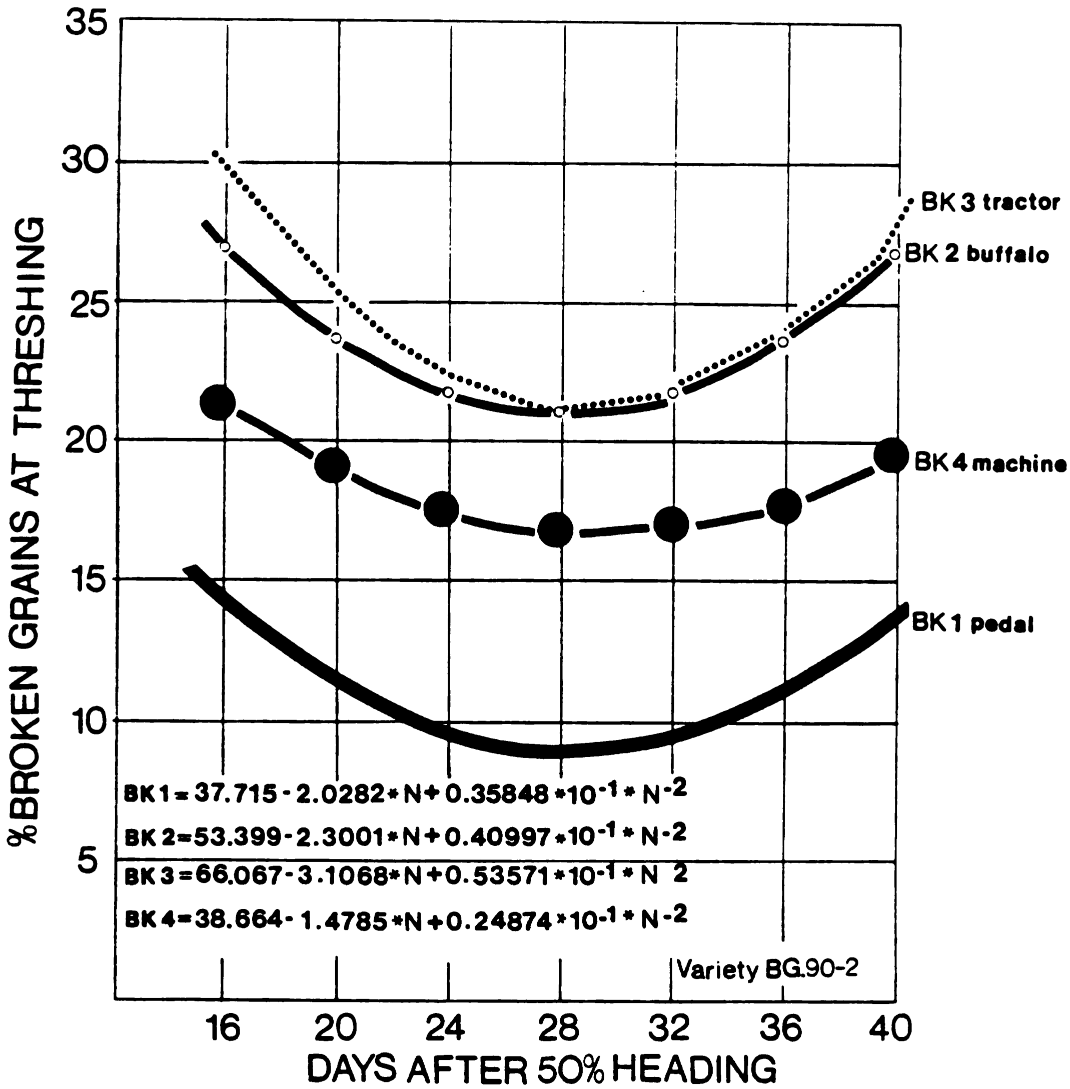


Figure 4.10 Percentage Broken Grains at Threshing - Variety BG. 90-2

Regression curves for the four threshing methods on variety H-4 are illustrated in Figure 4.11.

BG. 94-1

Equation (4.60) is a prediction equation for the percentage of broken grains using a pedal drum to thresh variety BG. 94-1.

$$BK1=10.106-0.37729*N+0.72396*10^{-2}*N^2 \qquad (4.60)$$

had a r^2 value of 0.4341 and its regression coefficients a_1 and a_2 were both significant at $t(\alpha=0.5)$.

Equation (4.61) is a predictor of broken grains using buffalos for threshing BG. 94-1 paddy,

$$BK2=45.168-2.7847*N+0.50219*10^{-1}*N^2 \qquad (4.61)$$

had a r^2 value of 0.9061 and its regression coefficients were significant at $t(\alpha=0.01)$.

A prediction of the percentage broken grains using a tractor for threshing is given by,

$$BK3=65.710-4.1471*N+0.77083*10^{-1}*N^2 \qquad (4.62)$$

which had a r^2 of 0.8416 with its regression coefficients significant at $t(\alpha=0.02)$.

Equation (4.63) predicts the percentage broken grains using a machine as a means of threshing.

$$BK4=86.702-5.4930*N+0.92772*10^{-1}*N^2 \qquad (4.63)$$

had a r^2 of 0.8949 and its coefficients were significant at $t(\alpha=0.01)$, Figure 4.12.

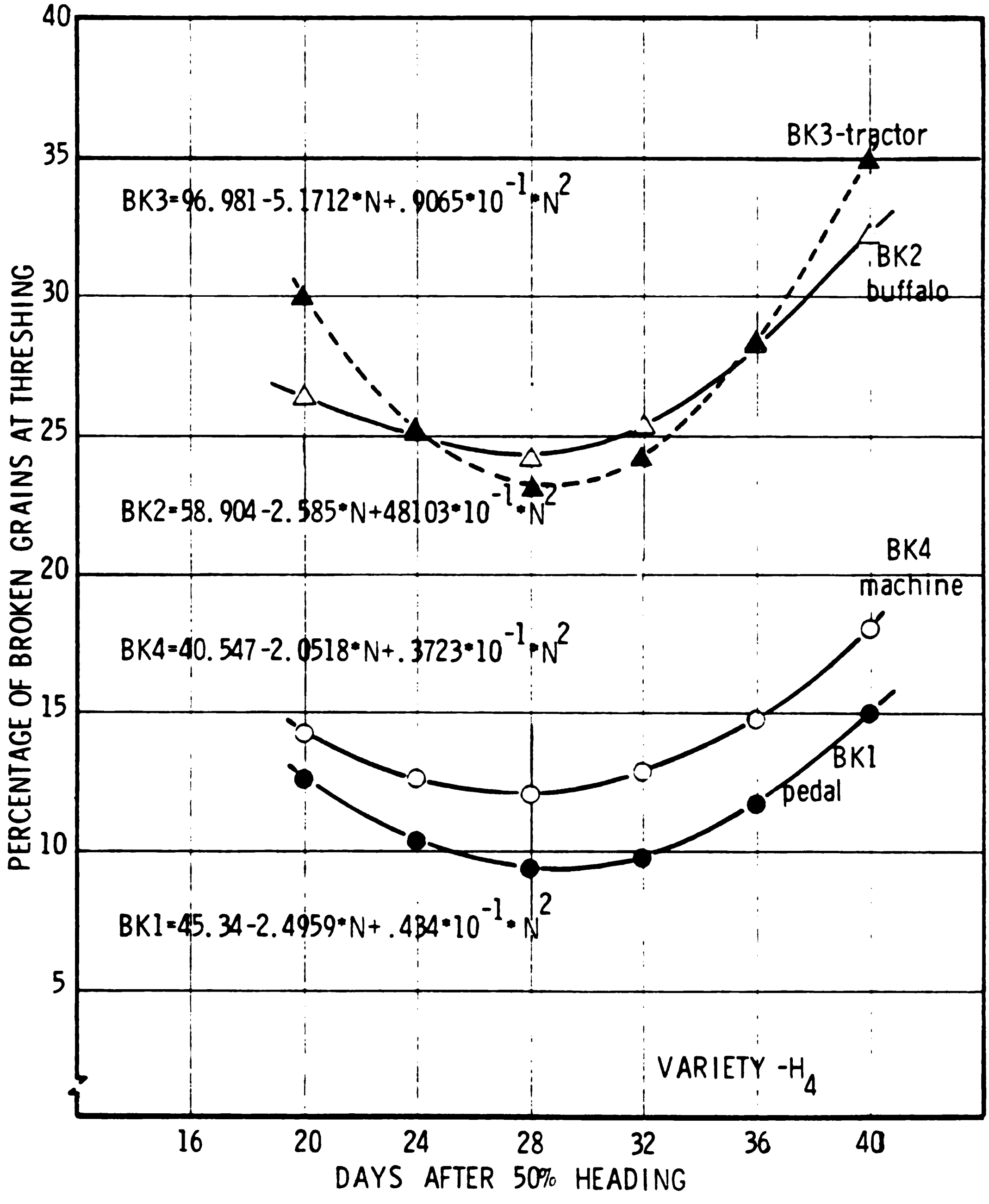


Figure 4.11 Percentage Broken Grains at Threshing - Variety H-4

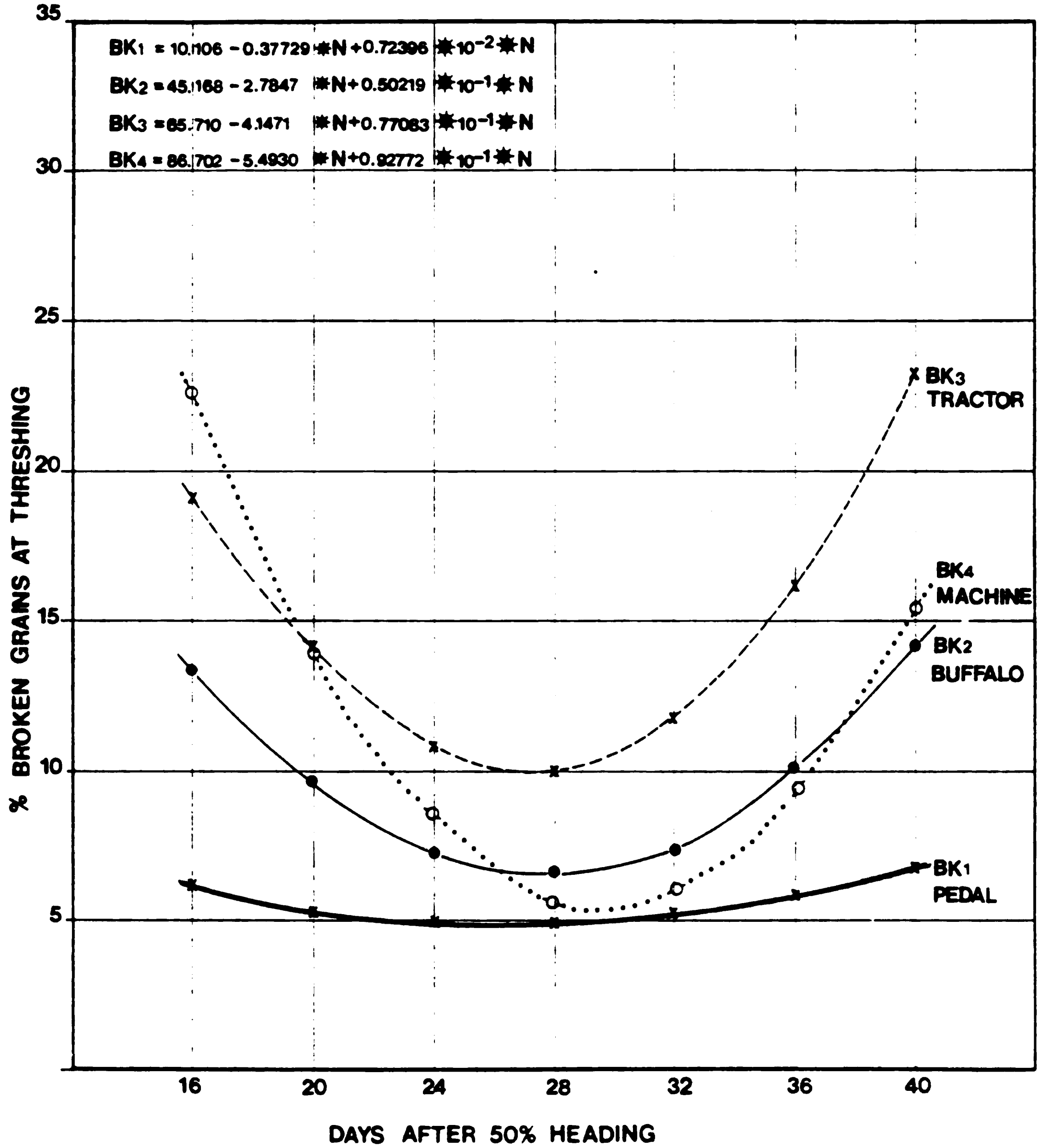


Figure 4.12 Percentage Broken Grains at Threshing - Variety BG. 94-1

DISCUSSION

The moisture content of the different varieties decreased with the onset of maturity and thereon. The moisture content of BG. 34-8 and BG. 94-1 seemed to decrease faster than that of the three varieties BG. 90-2, BG. 11-11 and H-4. This could be due to a varietal characteristic accompanied by the growth duration of each variety. BG. 34-8 and BG. 94-1 were both short aged varieties with growth durations of 3 to 3-1/2 months. The grain moisture in these varieties decreased faster than the longer aged varieties such as BG. 11-11, BG. 90-2 and H-4, having growth durations of 4 to 4-1/2 months, (Table 4.2).

Losses before cutting as well as all handling operations, such as cutting, bundling and transport showed an increase in grain loss with a delay in harvest, beyond the 16th day after 50% heading. BG. 34-8 and BG. 11-11 had a higher rate of losses as seen in the prediction equations of Figures 4.2 to 4.7. BG. 90-2 and H-4 had a lower loss rate which reflected the behavior of varietal characteristics in the shattering of grain during handling. Delays in harvesting dates were accompanied by the decrease in moisture content as well as the maturity of the plant, panicles and pedicels. The reduction of moisture and an increase in the maturity of the plant weakened the attachment of the pedicel with the grain, increasing its susceptibility to shattering at handling.

Losses due to birds and rodents were seen to increase with the increase in maturity and decrease in grain moisture content, Figure 4.7. However, BG. 34-8 which has a higher tendency to shatter with delays in harvest dates had lower losses due to birds and rodents throughout the period from 16 to 40 days after 50% heading. H-4, as a varietal characteristic, has a low tendency to shatter, however, as seen in Figure 4.7. H-4 showed a higher loss rate than BG. 90-2 or BG. 34-8. This indicated that varietal characteristics did not entirely influence the losses due to birds and rodents, but that losses could arise as a result of the level of bird and rodent infestation in a given area. H-4 plants lodged at the grain filling stage and were exposed to rodent damage from there on. Similarly, fields grown with BG. 11-11 had a high infestation of birds which fed on the grain from the stage of grain filling to maturity and thereon. Losses by birds and rodents were also influenced by the presence of humans within the proximity of the fields. Fields with variety BG. 34-8 were surrounded by houses which resulted in a regular movement of people on and around the fields. Bird and rodent losses were therefore less.

The percentage of broken grains varied with the methods of threshing. Figures 4.8 to 4.12 illustrate the influence of threshing method and harvest dates on the percentage of broken grains. The pedal thresher in all varieties showed a low tendency to produce cracked grains at threshing, while the tractor and buffalo threshing methods increased the percentage of broken grains. In most varieties the minimum breakages occurred around the 28th day after 50% heading, indicating that grains harvested around the stage of maturity had a higher resistance to breakage. Grains harvested before complete maturity tended to crack as a result of the forces at threshing. Similarly, grains that are harvested beyond the stage of maturity tended to be brittle and were prone to higher breakages as a result of threshing forces.

Regression equations from the analysis of field data were used in Chapter V to provide predictive equations to simulate the in-field post production.

CHAPTER V

THE IN-FIELD POST PRODUCTION SUBSYSTEM MODEL DEVELOPMENT

The model was formulated to represent the cutting, bundling, transport and threshing operations of the farm level rice post production system. A weather model simulated daily rainfall patterns for the farm area and illustrated its effect on the post production operations. Labor was distributed to the different operations by a labor model simulating the effects of labor availability on post production operations. Losses in handling due to the different production operations were simulated during the cutting, bundling and transport operations. Chapter V describes the overall model and the development of the individual operational models for cutting, labor, weather, bundling, transport and threshing.

5.1. Theory and Derivation of Equations for the Model.

All operations such as cutting, bundling, transport and threshing were time related, each being assigned a rate to perform the given operation. All the rates were calculated as area per time or ha/hr. Therefore, the integral of a rate within a time interval gave the area covered by the operation in that specified time limit.

If r was the rate of an operation and x the area covered by the operation from T=0 to t , then

$$x(t) = \int_{o}^{t} r\,dt \tag{5.a}$$

If the operation was either a -ve summation or a +ve summation on a time interval, T=0 to t, and the integral of the rate was either added or subtracted to the previous value (t=0) of the operation, the equation was represented as,

$$x(t)=x(0)\pm \int_{o}^{t} r\,dt \tag{5.b}$$

If rr was the rate of another operation affecting the -ve or +ve summation of operation X, a change in X for a given time interval, T=0 to t, was,

$$x(t)=\int_{o}^{t}(rr-r)\,dt$$

or, as in (5.b)

$$x(t)=x(0)\pm\int_{o}^{t}(rr-r)\,dt \tag{5.c}$$

Many useful predictor type formulae have been developed to find solutions to differential equations. Of these, Euler's formula, based on Euler's methods for the solution of differential equations, was used in this chapter. Euler's formula is a predictor, in that it predicts a value for a $\int_{t}^{t+DT} f(x)dx$ on the basis of values of f(X) at a time prior to (t+DT). For a small increment of time DT, Euler's formula was given as,

$$F(t+DT)=F(t)+DT*F'(t)+\xi$$

where ξ was the error term.

To represent (5.b) and (5.c) in integral form suitable for numerical integration,

from (5.b), $$x(t+DT)=x(t)\pm\int_{t}^{t+DT} r.dt \tag{5.d}$$

from (5.c), $$x(t+DT)=x(t)\pm\int_{t}^{t+DT} (rr-r)dt \tag{5.e}$$

For ease in computer simulation (5.d) and (5.e) were rewritten as,

from (5.d), $X'=X\pm R*DT$

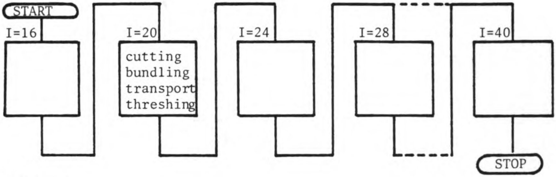
from (5.e), $X'=X\pm(RR-R)*DT$

Where X' was the area of operation after a time increment DT and X the area before time increment DT.

All equations having a rate related function in the simulation model were solved by Euler's formula for solving differential equations. Euler's approach has shown to be entirely adequate for many simulation applications where a very high solution accuracy was not necessary. The Euler approach, by its simplicity, reduced the time and effort required in the development of operating models, (Manetsh and Park, 1974).

5.2. The Overall Model.

A variety of known maturity dates, shattering and lodging characteristics grown on a known area of land were used as inputs to the model. The variety under study was harvested at a predetermined date, initially at 16 days after 50% heading. The known land area was harvested,



i=16 to 40
I=cutting date

Figure 5.1 Cutting Sequence of the Overall Model

bundled, transported and threshed using one of four threshing methods. The harvesting, bundling, transporting and threshing operations were influenced by the outcome of the weather and labor models which may have caused delays in the operational procedures. The model was run from the 16th day after 50% heading and the losses in each operation were calculated for harvests beginning on that day. After completion of all post production operations the model continued to harvest a similar land area every fourth day, on an interval of I=16 to I=40, as illustrated in Figure 5.1. The fortieth day was taken as the period of complete maturity beyond which many fields were not left unharvested by farmers.

In each of the post production subsystems, where cutting was initiated on the Ith day, a complete operational procedure from cutting to threshing took place, subject to the influences of rain and labor. The number of days

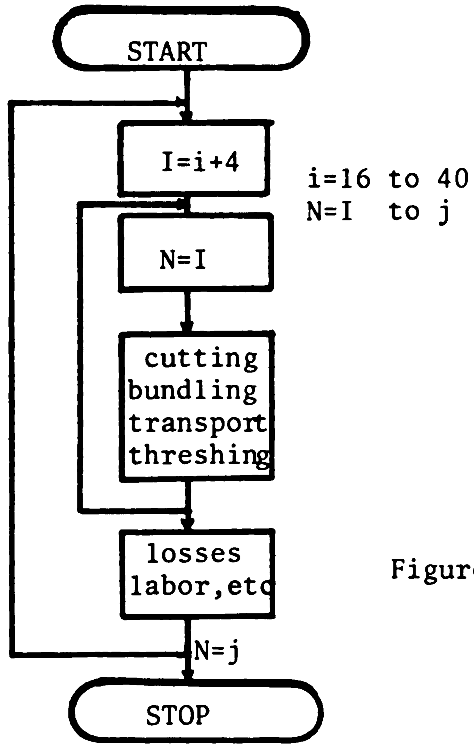


Figure 5.2 Cutting Sequence of Individual Post Production Model

required to complete this post production process, N, varied in each Ith operation and influenced losses due to delayed operational procedures brought about by climatic conditions and labor shortages. The output of each Ith operation was the total grain loss, total bad days and total labor use during the post production period from $N=I_i$ to $N=N_j$, where I_i was the initial cutting date and N_j the day the final operation was completed, Figure 5.2. The overall in-field post production subsystem is illustrated in Figure 5.3.

5.3. The Cutting Model.

The cutting operation for the total planting area RLAND began at $N=I_i$ if the labor for cutting, LABH, was greater

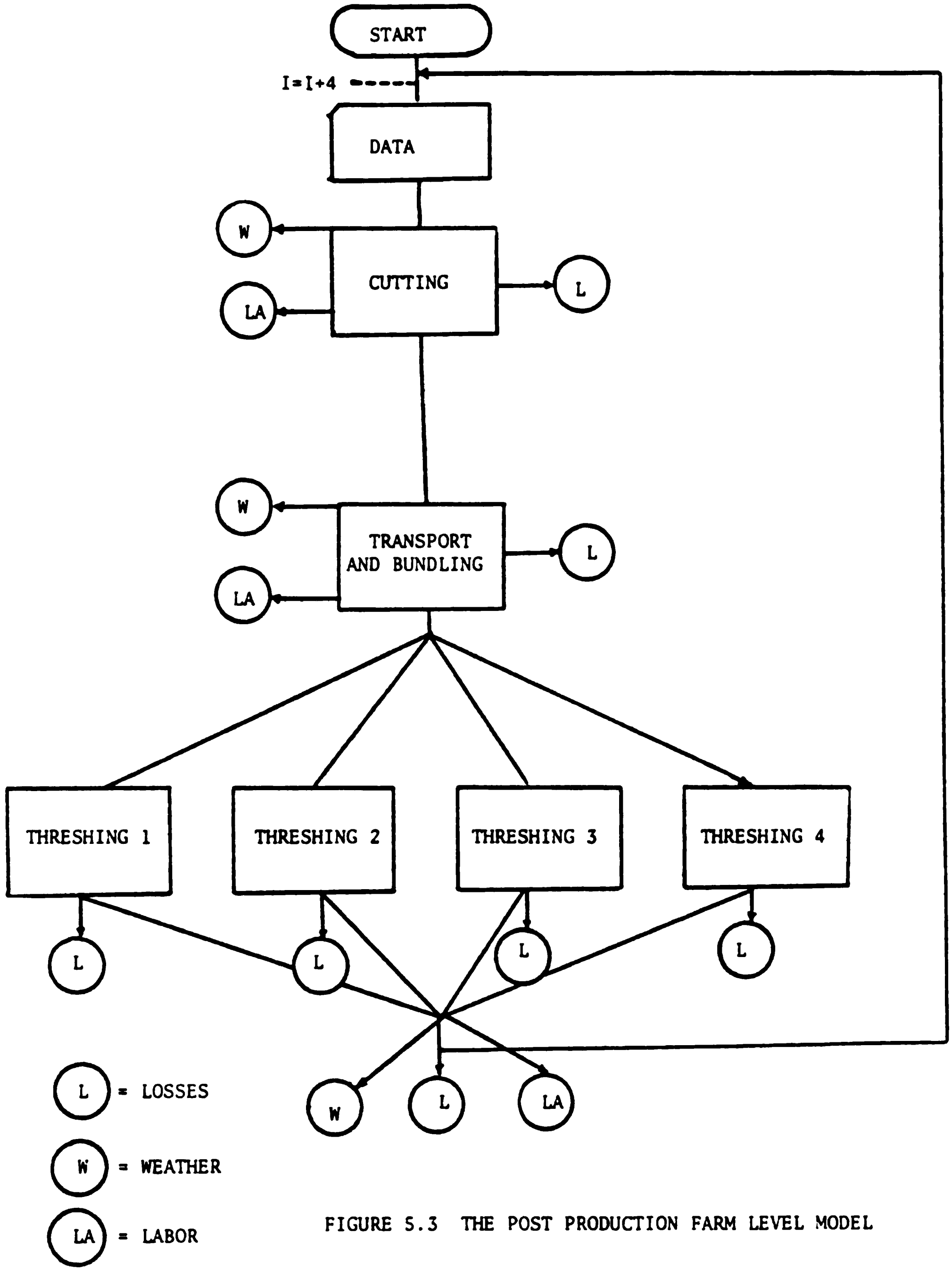


FIGURE 5.3 THE POST PRODUCTION FARM LEVEL MODEL

than 4 and if there was no rain, R=0, on the cutting day. If labor was less than 4, harvesting was postponed to the next day. Similarly, if there was rain and R=1, cutting was postponed to the next day. The cutting operation commenced only after the conditions, LABH>4 and R=0, were satisfied, Figure 5.4.

Pre-harvest losses were those losses occurring on unharvested land prior to complete harvesting in kg/ha. Preharvest grain losses PHV, were calculated using one of the prediction equations 4.14 to 4.18, depending on the variety under test. TPHV was the grain loss in kg for the total unharvested land area and computed with equation (5.1).

$$TPHV=PHV*(RLAND-DH) \quad (5.1)$$

where DH was the area harvested in ha.

The total grain loss PHVT in kg for the unharvested area, influenced by delays in harvesting, rain and labor factors, was,

$$PHVT=\sum_{n=i}^{j} TPHV$$

or

$$PHVT=PHVT+TPHV \quad (5.2)$$

The percentage of sunchecks, SNC, was calculated using one of the equations 4.8 to 4.12, depending on the variety under test.

Bird and rodent losses, BRD, were calculated using one of the predictive equations 4.38 to 4.42, depending on the

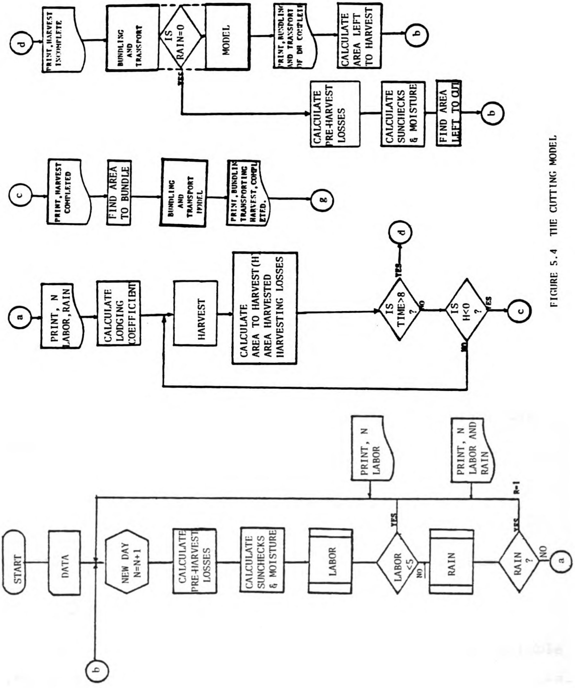


FIGURE 5.4 THE CUTTING MODEL

variety under test. TBRD was the total bird and rodent losses in kg for the unharvested land area and given by equation (5.3) as,

$$TBRD=BRD*(RLAND-DH) \qquad (5.3)$$

The total grain loss BRDT in kg of the unharvested area was computed as,

$$BRDT=\sum_{n=i}^{j} TBRD$$

or

$$BRDT=BRDT+TBRD \qquad (5.4)$$

5.4. The Labor Model.

The LABOR subroutine assumed that available labor would follow a Gaussian or normal distribution. The probability density function for the normal distribution was given as,

$$f(x)= \frac{1}{\sqrt{2}\,\sigma_x^{2}} e^{-(x-u_x)^2/2\sigma_x^2}$$

where u_x= the mean or expected value of the random variable X and

σ_x= the standard deviation of X

Y was taken as a "standardized" normal random variable with zero mean and standard deviation of one. The standardized random variable was transformed into a normal variable having a desired mean and standard deviation, using equation (5.5).

$$X = \sigma_x y + u_x \tag{5.5}$$

The following method was used to compute normal random variables with a specified mean and standard deviation, (See Appendix A2).

1. A uniform random variable (0,1) was generated using subroutine GGUB (IMSL File for IBM 370)-r_i.

2. A standardized normal random variable y_i was generaged where,

   y_i=FNL(NMLVAL,0.,.025,40,r_i)

   FNL (Appendix A3) is a subprogram which constructs a piecewise linear approximation for the inverse normal cumulative distribution function, using the array NMLVAL (Appendix A2). The array NMLVAL contains the ordinates of the inverse normal cumulative distribution, (Manetsch and Park, 1974).

3. A normal random variable x_i was computed with the desired mean u_x and standard deviation σ_x from equation (5.5).

4. LM (the available labor) was made equal to x_i and returned as available labor to the main program.

LABH, the labor for the cutting operation, was computed by equation (5.6),

$$\text{LABH}=\text{LABF}+\text{LM} \tag{5.6}$$

where LABF is the available family labor (input).
The cutting operation specified that if LABH was less than 5, cutting was postponed to the next day and the process repeated until LABH was greater than 4 labor units. It was assumed that 5 units of labor was the minimum labor requirement to cut a given rice field. However, the labor, LM from the subroutine was supplemented with family labor, LABF serving as an input variable in the model. Family labor

varied between farm households and added to the generated hired or shared labor.

5.5. The RAIN Model.

The occurrence of rain or no rain was simulated using the model of Jones, Colwick and Threadgill (1972). Subroutine RAIN (Appendix A4) was formulated using rainfall records collected at the Dry Zone Research Station in Maha Illuppalama for a 20 year period, beginning in 1958. The functional relationship for simulating rainfall occurrence reported by Jones, et al. (1972) was given as,

$$R=f(W,\ Ra,\ RV) \qquad (5.6)$$

where R = rainfall for the day

w = time of the year (week)

Ra= rainfall from the previous day

RV= other random variables

A Markoff chain model was used in calculating the probability of rain for a given day. The theory of Markoff chains is concerned with probabilistic processes in which the outcome of a certain stage depends on the outcome of the immediately preceding trial, and only on it (Chorafas, 1965). The conditional probabilities of rainfall were calculated from the following equations.

$$Pm(i) = \frac{\sum \text{wet days following a wet day (i)}}{\sum \text{days following a wet day (i)}}$$

and

$$Pn(i) = \frac{\sum \text{wet days following a dry day (i)}}{\sum \text{days following a dry day (i)}}$$

where Pm(i) was the conditional probability that any day in the ith week will be wet, given that the previous day was wet; and Pn(i) was the conditional probability that any day during the ith week will be wet, given that the previous day was dry. Values of Pm(i) and Pn(i) were computed for each week of the two seasons, February to April and August to October respectively, considering only one antecedent day in calculating Pm(i) and Pn(i).

Harvesting operations for the Maha crop is done between February and April. The harvest of the Yala crop is performed between August and October. The scheduled harvesting dates are determined by variety and planting dates. The choice of a two season rainfall simulation is to predict bad days affecting the harvesting schedules of both Maha and Yala harvesting seasons.

Sixth order polynomial equations were fitted to both Pm(i) and Pn(i), (PWW and PWD respectively in the simulation) to predict these variables as functions of week number. An F test was performed to test the equations for significance and a coefficient of determination r^2 was calculated for each. PWD for season I (February to April) had a r^2 of 0.9477 and was significant at $F(\alpha=0.005)$ while

PWW had a r^2 of 0.5403 and was not significant at $F(\alpha=0.005)$ PWD for season II (September to October) had a r^2 of 0.9471 and was significant at $F(\alpha=0.005)$ while PWW had an r^2 value of 0.6092 and was significant at $F(\alpha=0.5)$. Figures 5.5 and 5.6 illustrate actual and predicted values for Season I and II respectively, using polynomial regression equations, (5.7), (5.8), (5.9) and (5.10).

Season I

$$PWW(W)=2.0356-2.7443*W+1.5785*W^2-0.40824*W^3+0.52509*10^{-1}*W^4-0.32797*10^{-2}*W^5+0.79313*10^{-4}*W^6 \quad (5.7)$$

$$PWD(W)=0.70806-1.1123*W+0.69947*W^2-0.20151*W^3+0.28819*10^{-1}*W^4-0.19758*10^{-2}*W^5+0.51777*10^{-4}*W^6 \quad (5.8)$$

Season II

$$PWW(W)=-0.3268+1.1270*W-0.58463*W^2+0.14450*W^3-0.18613*10^{-1}*W^4+0.12104*10^{-2}*W^5-0.31212*10^{-4}*W^6 \quad (5.9)$$

$$PWD(W)=-0.32616+0.82034*W-0.53105*W^2+0.15312*W^3-0.21656*10^{-1}*W^4+0.14766*10^{-2}*W^5-0.38715*10^{-4}*W^6 \quad (5.10)$$

where W is the week number of the year. Considerable variations in PWW were seen in Seasons I and II although both PWW and PWD for both seasons show definite weekly trends. It was assumed, however, that little variations occurred within the week and each day in the given week was treated as having equal probabilities of either PWW or PWD.

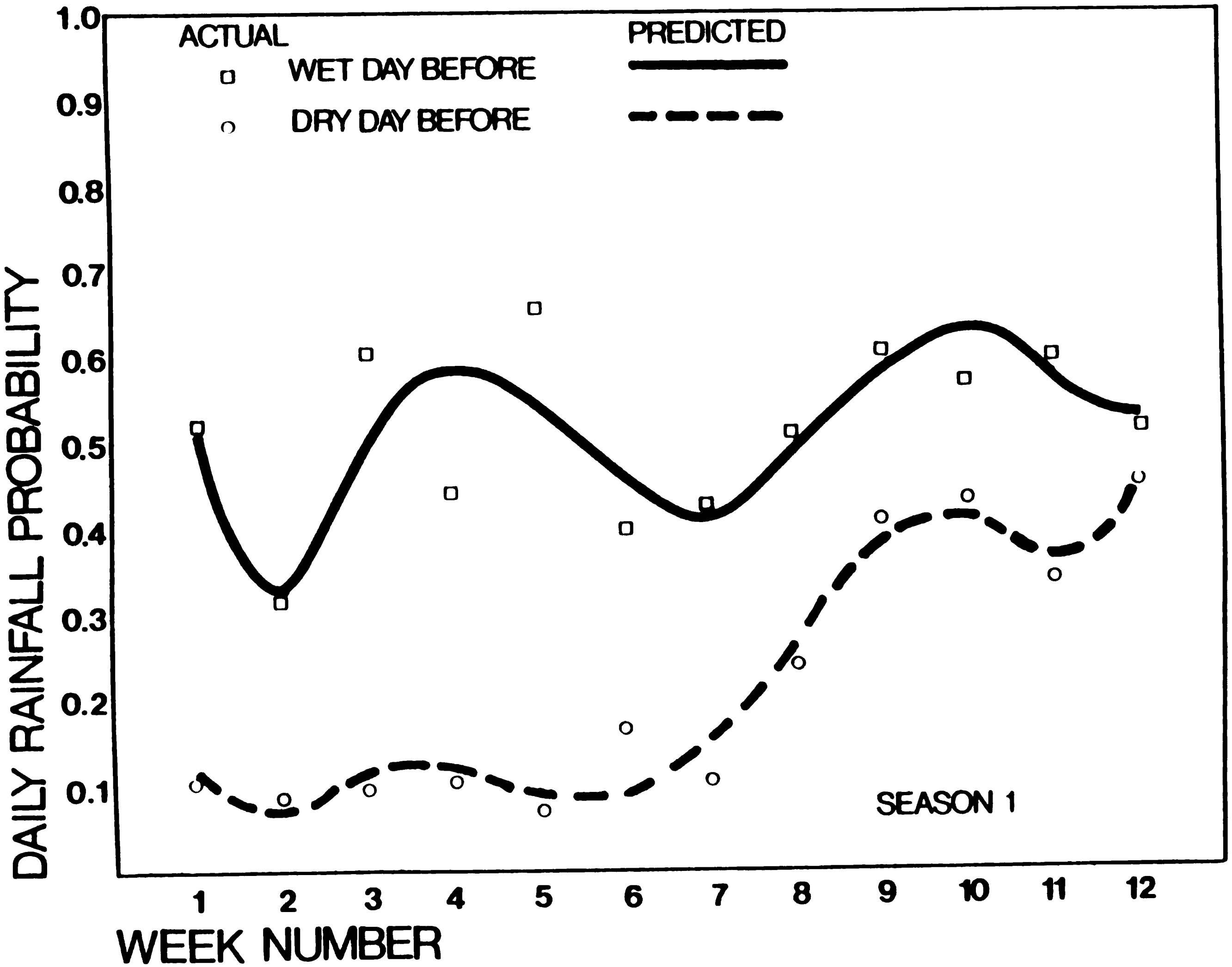


Figure 5.5 Actual and Predicted Rainfall Probabilities from Regression, Season I

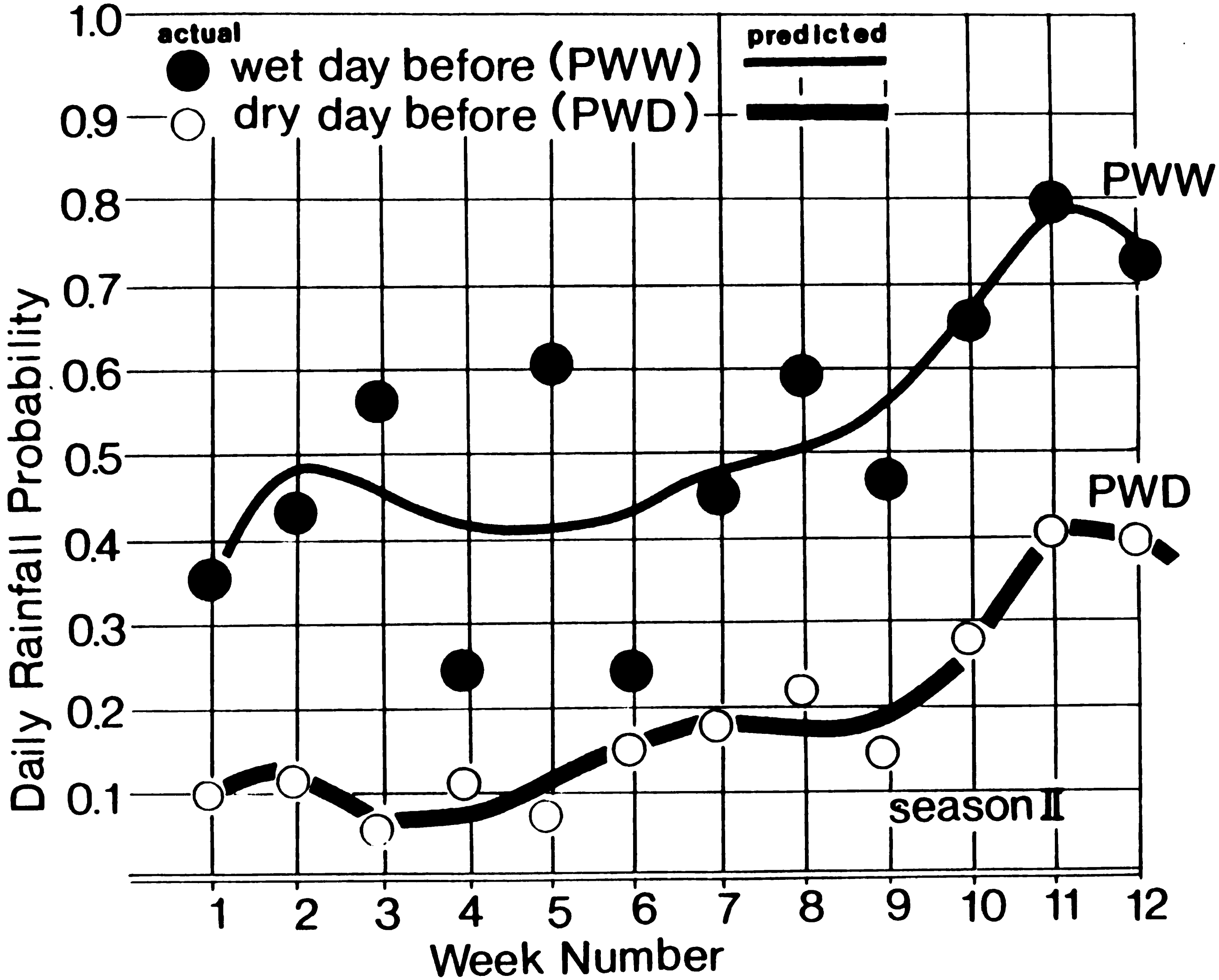


Figure 5.6 Actual and Predicted Rainfall Probabilities from Regression, Season II

The probability of rain (R=1) and no rain (R=0) was simulated using the model illustrated in Figure 5.7 and Appendix A4. Weather is an important factor in the cutting operation. Cutting will not take place if it rains on the proposed cutting date. Cutting was postponed to the next day or repeatedly postponed until R=0 in the harvesting model. The subroutine was called at the start of all cutting operations.

If labor and weather conditions were satisfied the cutting operation was performed starting in the morning of an eight hour work day. The cutting rate RH of 0.013 ha/hr/labor unit was calculated by observing the area cut by seven men in two hours. It was assumed in the model that the cutting rate remained uniform throughout the operation. RRH was the cutting rate by the total labor force LABH. A lodging factor RLODG of 0.0, 0.25 and 0.50 was used respectively for varieties that do not lodge, lodge partially and lodge completely. A lodging coefficient RLDG was computed from the equation,

$$RLDG=1.0-RLODG \tag{5.11}$$

and was used to reduce the cutting rate. For example, if the plants lodged partially, the factor was 0.25 and RLDG from (5.11) was 0.75. The cutting rate was taken as,

$$RRH=RH*LABH*.75 \tag{5.12}$$

$$RRH=RH*LABH*.50 \qquad \text{if } RLODG=.5$$

$$RRH=RH*LABH*1.0 \qquad \text{if } RLODG=0.0$$

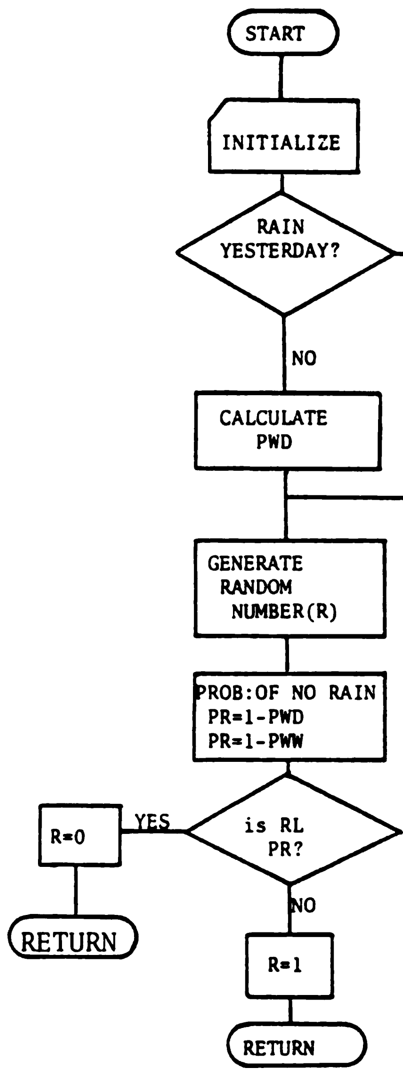


FIGURE 5.7 RAIN SUBROUTINE TO SIMULATE OCCURRENCE OF RAIN (R=1) OR NO RAIN (R=0)

The area H in HA that remained to be cut at a time T was given by

$$H(T)=H(0) - \int_0^T (RRH*RLDG)dt \tag{5.13}$$

or for time increments of DT

H=H-RRH*DT*RLDG

DH was the total area in HA harvested at time T and given by

$$DH(T)=DH(0)+ \int_0^T RRH*RLDG*dt \tag{5.14}$$

or for time increments of DT

DH=DH+RRH*DT*RLDG

Cutting losses PSV were losses at the time of cutting in kg/ha. PSV was calculated using equations 4.20 to 4.24, depending on the variety under study. TPSV was the grain loss in kg for the harvested area DH at time t and computed with equation (5.15).

TPSV=PSV*RRH*DT*RLDG (5.15)

The total grain loss PSVT in kg for the harvested area at time T was

$$PSVT=\sum_{t=1}^{T} TPSV \tag{5.16}$$

or

PSVT=PSVT+TPSV

A work day was assumed to have eight hours. If the cutting time exceeded the 8th hour, the cutting operation was incomplete and was continued the next day. If H=0.0, before T=8, then cutting was complete on day N and the cut sheaves were allowed to dry on the field until the next day, (N=N+1). If H>0 and T>8, the cutting operation was incomplete and the operation was carried on to the N+1 day provided that R=0. If N+1 was a rainy day, ie R=1, the stalks cut during day N were transported and stacked. All available labor generated by the labor model, in addition to family labor, was used in the transport of cut sheaves.

If the total area DH, cut during N was not bundled and transported at N+1 and R=0 at N+2, the unharvested area was cut. If the harvest was incomplete the cycle was repeated until the harvest was completed. If R=1 at N+2, bundling and transporting was continued until the area DH was transported.

After completing the harvest operation the stalks were left for drying on the field. If N+3 was a rainy day, then the remaining stalk was bundled and transported. If bundling and transport was incomplete at N+3 and R=0 at N+4 , bundling, transporting and pedal threshing were performed at N+4 if the pedal thresher was used for threshing. If R=1 at N+4, the remaining stalk was bundled and transported. The transported stalk was threshed from N+5 onwards, Figure 5.8.

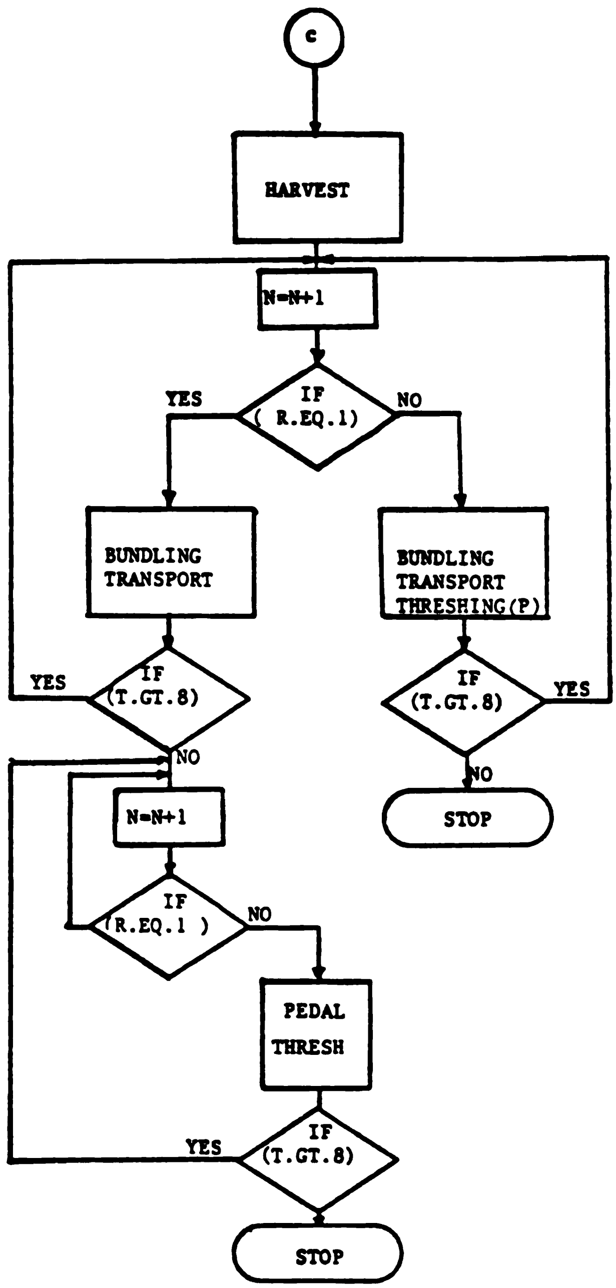


Figure 5.8 Bundling, Transport and Pedal Threshing as Affected by Rain

5.6. The Bundling and Transport Model.

Any sheaves left on the field beyond a day after the cutting operation were assumed to be bundled and transported even if R=1. The cut sheaves were transported and stored even though R=1, to avoid spoilage of cut bundles on the field. The RAIN subroutine predicted the possibility of cutting the unharvested area if R=0.0.

Labor was simulated using the LABOR subroutine and used to bundle and transport the cut stalk simultaneously. No limitations were placed on labor availability for the operation. Labor generated by LABOR was used by the model, supplemented with input family labor, LABF. Priority was given to remove the cut sheaves left behind on the field and therefore any labor available was used for these operations. LAB was the total labor available for the bundling and transport operation.

LAB=LM+LABF (5.18)

Two-thirds of the available labor was used for the transport operation, while the balance being used for the bundling operation,

LABT=(2/3)*LAB (5.18)

where LABT is the labor for transport

LABB=LAB-LABT (5.19)

where LABB is the labor for bundling

The transport rate TR in ha/hr was based on the time taken to carry a known area of harvested stalk to a known distance. On an average an equivalent area of about 25 square meters of stalk was carried on a single trip to the threshing floor. TR=0.009 ha/hr was calculated using equation (5.20) from observed data, (Appendix A5). TR was assumed to be uniform throughout the transport operation.

$$TR=S/D*(1/2)*B \tag{5.20}$$

where S= average speed of labor unit, m/hr.

D= average distance to threshing floor, m.

B= average area in a bundle of cut stalk head carried by a farmer, ha.

Equation (5.20) was divided by 2 to calculate the average number of trips from the field to the threshing floor. The rate of bundle removal used as the transport rate, was the area of cut stalk transported from the field to the threshing floor, at a given time, t.

TRR, ha/hr was the transport rate utilizing the total labor LABT for the transport operation, given by,

$$TRR=TR*LABT \tag{5.21}$$

The bundling rate BR, ha/hr, calculated from field observations, (Appendix A6), was the area of cut sheaves, bundled per hour by a single labor unit. BRR in ha/hr was the bundling rate by the total labor, LABB for the bundling operation, equation (5.22).

$$BRR=BR*LABB$$

Since both operations were performed simultaneously, if TRR>BRR, at every time increment DT, labor for transport remained idle until bundles were made to be transported. A check was necessary to reduce TRR and increase BRR in the event that TRR>BRR. The following statements were used to make this check.

```
100 CONTINUE
    TRR=TR*LABT
    BRR=BR*LABB
    IF(TRR.GT.BRR)   LABT=LABT-1
    IF(TRR.GT.BRR)   LABB=LABB+1
    IF(TRR.GT.BRR)   GO TO 100
```

A was the area in ha of sheaves left to be bundled at time T and given in equation (5.23) as

$$A(T)=A(0) - \int_0^T BRRdt \tag{5.23}$$

or for the increments of DT

A=A-BRR*DT

The area bundled at a time increment of DT was given as BN, in equation (5.24)

$$BN=BRR*DT \tag{5.24}$$

The total area bundled BND in ha, at a given time T was calculated by (5.25)

$$BND(T)=BND(0)+\int_0^T BRRdt \tag{5.25}$$

or for time increments of DT

BND=BND+BRR*DT

Bundling losses BNDL, are losses at the time of bundling kg/ha. BNDL was calculated using equations 4.26 to 4.30 depending on the variety under study. TBNDL was the grain loss in kg for the area bundled at time t and computed from (5.26)

$$TBNDL=BNDL*BN \tag{5.26}$$

The total grain loss in kg for the total bundled area at time T was computed from,

$$BNDLT=\sum_{t=1}^{T} TBNDL \tag{5.27}$$

or

$$BNDLT=BNDLT+TBNDL$$

The area remaining to be transported AT in ha, at time T is a function of the area bundled BN, the transport rate, TRR at T, and the area to be transported at T-1, equation (5.28).

$$AT(T)=AT(0)+\int_0^T (BRR-TRR)dt \tag{5.28}$$

or for time increments of DT

$$AT=AT+(BRR-TRR)*DT$$

The area transported ATR in ha, for a time T was represented by equation (5.29)

$$ATR(T)=ATR(0)+\int_0^T TRRdt \tag{5.29}$$

and for a time increment of DT

$$ATR=ATR+TRR*DT$$

Losses due to transport TRL in kg/ha were calculated by equations 4.32 to 4.36 depending on the variety under test. TTRL was the grain loss in kg for the transported area at time t, equation (5.30)

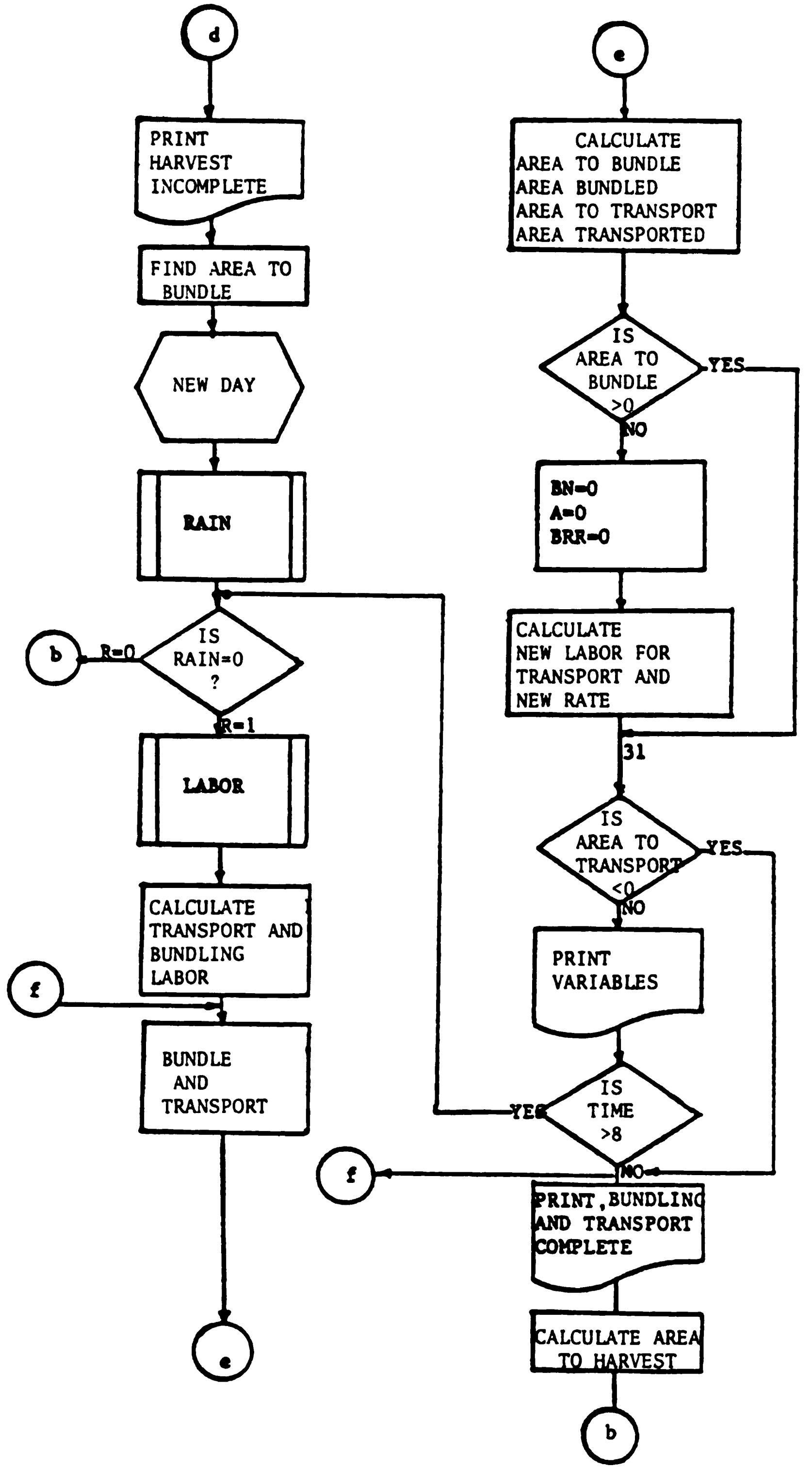


Figure 5.9 Bundling and Transport Model

TTRL=TRL*TRR*DT (5.30)

The total grain loss in kg for the total transported area at time T is

$$TRLT=\sum_{t=1}^{T} TTRL \qquad (5.31)$$

or

TRLT=TRLT+TTRL

When A, the area to be bundled, was reduced to 0.0, bundling was completed and BN=0.0. The bundling rate, BRR=0.0 and the labor for bundling, LABB joined the labor for transport, LABT so as to increase the transporting labor, LABBT, Figure 5.9. The transporting rate, TRR was increased and is given by,

TRR=TR*LABBT (5.32)

As BRR=0.0, BN=0.0, the area to be transported AT started decreasing with the increased TRR. From (5.28)

ie. AT=AT+(0.0-TRR)DT

When AT reaches 0.0, bundling and transport was completed and the model was ready to commence the threshing operation.

If T>8, A>0.0 and AT>0.0, bundling and transport was not completed within the 8 hour working day. The operation was carried on to the next day (N+1). If T>8, A<0.0 and AT>0.0, bundling of the stalk was completed but transport was not. Stalk was transported on N+1 subsequent days until AT=0.0. If T<8, A<0.0 and AT<0.0, bundling and transport had been accomplished within the eight hour working day.

5.7. Threshing Models.

Four methods of threshing were used in the overall model, a) pedal, b) buffalo, c) tractor and d) machine. Of these, tractor, buffalo and mechanical threshing were performed after all the cut stalk had been transported to the threshing floor, whereas pedal threshing was performed on the field or, depending on weather conditions, on the threshing floor, Figure 5.8.

a) Pedal Threshing

Pedal threshing was performed on the field if R=0.0. Bundling, transport and pedal threshing were done simultaneously. Bundling and transport operation was first performed as in equations (5.23), (5.24), (5.25), (5.28), (5.29) and (5.33). The area to be pedal threshed APT in ha was equal to the amount transported ATR in ha. Grain loss from bundling and transport was calculated in the threshing model, using equations (5.26), (5.27), (5.30) and (5.31).

The area transported ST, at time increment DT added on to APT, the area to be threshed, for every DT (5.33), until AT=0.0. When AT=0.0, transportation

$$ST=TRR*DT \qquad (5.33)$$

was completed and TRR=0.0. Therefore, ST=0.0.

The area remaining to be pedal threshed, APT, was a function of the area transported, ST, the threshing rate, TRTP at T and the area that was to be pedal threshed at T-1, equation (5.34).

$$APT(T)=APT(0)+\int_0^T (TRR-TRTP)dt \tag{5.34}$$

or for the time increment DT

APT=APT+(TRR-TRTP)*DT

The rate of pedal threshing TPT in ha/hr was calculated from field observations, Appendix A7. Three units of labor were assumed to be used to operate the machine on a rotating principle, i.e. a man picks a bundle, walks up to the thresher, threshes the bundle and moves out. A second man, meanwhile, has picked another bundle and threshes it after the first man moved out. The third man performs a similar task, after which the first man is ready to thresh a fresh bundle of stalk. LABPT, the labor units for pedal threshing, varies and was used as an input variable.

TRTP, the total rate of pedal threshing for labor units performing the operation, was given as,

TRTP=TPT*LABPT (5.35)

The area pedal threshed, ATT, for a time T was,

$$ATT(T)=ATT(0)+\int_0^T TRTPdt$$

and for a time increment DT,

ATR=ATR+TRTP*DT

If A=0.0, AT=0.0 and APT>0.0 when T>8, bundling and transport was completed, but pedal threshing was incomplete for the eight hour day. The stalks were threshed on the next day and the process repeated until APT=0.0. Threshing was then complete and so were the other operations, cutting bundling and transport, Figure 5.10.

Pedal threshing may be continued following the bundling and transport operation. If rainy weather prevailed during the bundling and transport operations, pedal threshing was not performed on the field. After all the stalk was transported the stalk threshing was done the next day provided that R=0.0.

The area to be threshed, APT, was equal to the total area transported, ATR. As the transport operation was complete, TRR=0.0 making ST=0.0. The area to be threshed at a time T was therefore,

$$APT(T)=APT(0)-\int_0^T TRTPdt \qquad (5.37)$$

or for time increment DT by Euler integration,

APT=APT-TRTP*DT

The area threshed at time T was,

$$ATT(T)=ATT(0)+\int_0^T TRTPdt \qquad (5.38)$$

or for time increment DT

ATT=ATT+TRTP*DT

If APT<0.0 and T<8, threshing was completed within the eight hour day. It T>8 and APT>0.0, the stalk was threshed

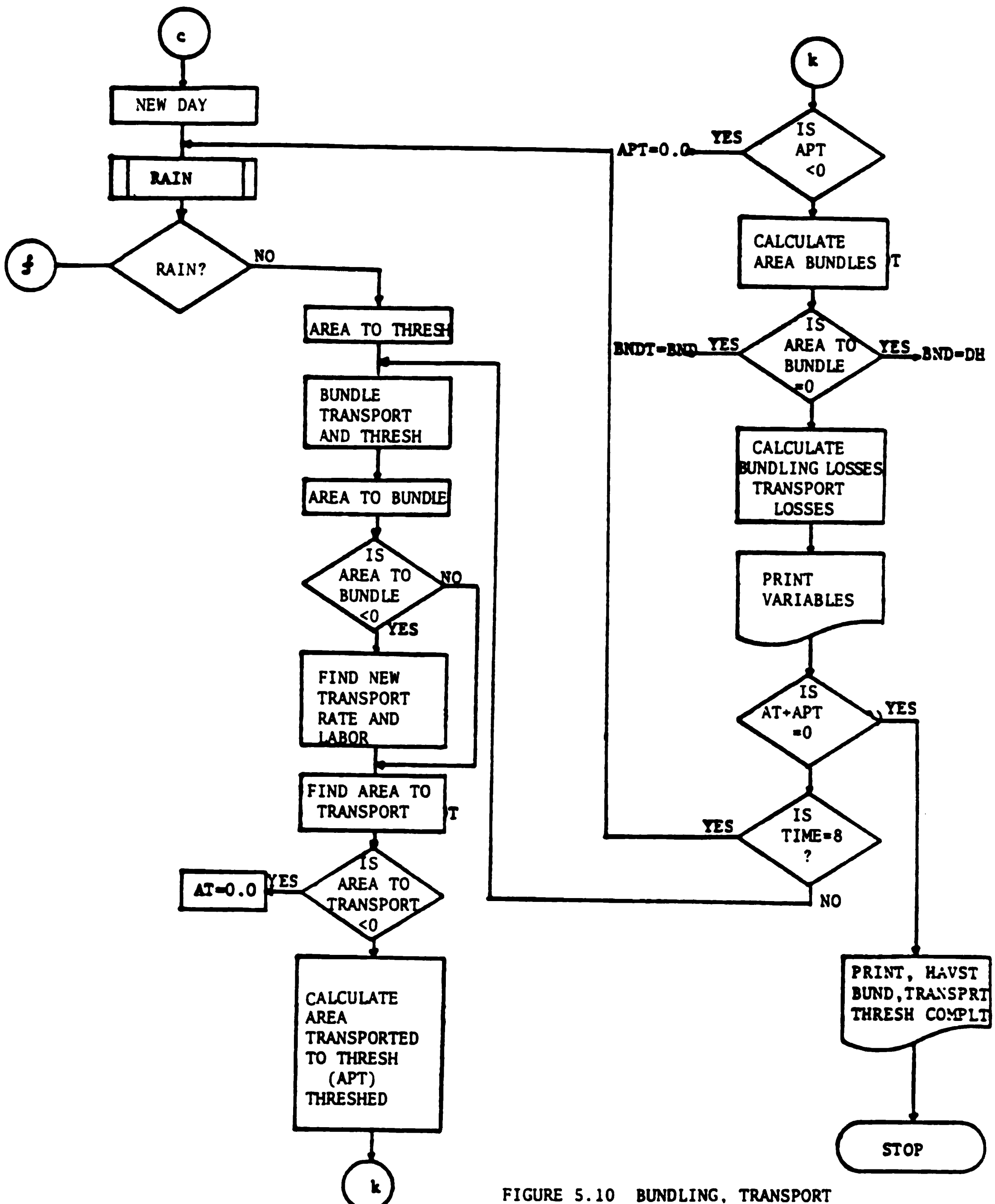


FIGURE 5.10 BUNDLING, TRANSPORT & PEDAL THRESHING MODEL

the next day, providing R=0.0. If R=1, the stalk was kept in stacks until a favorable day was available for threshing. When APT=0.0, cutting, bundling, transport and pedal threshing was complete.

b) Buffalo Threshing

The cut stalk was threshed by buffalos after being transported to the threshing floor. The area remaining to be threshed by buffalos, ABT in ha, was initially the area ATR transported in N days. Buffalos are usually available for threshing on a share basis between neighboring farmers, but in certain areas buffalos are hired on a fixed fee of Rs. 40 per working day.

The rate of buffalo threshing TB in ha/hr/pair of buffalos was an average observed under field conditions, Appendix A8, and assumed to be uniform in the model. The number of pairs available for threshing varies depending on the area of land initially harvested. The number of pairs for threshing, NBRP, was used as an input variable in the model.

The area to be threshed, ABT, for a given time, T, was represented in equation (5.39) as

$$ABT(T)=ABT(0)-\int_0^T TRTBdt \qquad (5.39)$$

where TRTB=TB*NBPR
NBPR being the pairs of buffalos available for threshing.

or for time increment DT

ABT=ABT-TRTB*DT

The area threshed by buffalos, ATTB in ha, at a given time, T, is

$$ATTB(T)=ATTB(0)+\int_0^T TRTB*T \qquad (5.40)$$

or for time increment DT

ATTB=ATTB+TRTB*DT

The stalk is threshed if it does not rain, i.e. R=0.0, on the scheduled threshing date. If R=1, threshing is postponed for the next suitable day. If ABT>0.0 and T>8, threshing was incomplete and was continued on N+1, provided that R=0.0. If ABT<0.0 and T<8, the operations, cutting, bundling, transport and threshing were complete, Figure 5.11.

c) Tractor Threshing

Tractor threshing was performed if R=0.0. One tractor was used for each threshing operation at a fee of Rs. 85 per working day. Tractors were usually rented from a tractor owner who may or may not have his own rice fields. The stacks of cut stalk were kept on the threshing floor until a tractor was available and the weather was favorable for threshing.

The rate of tractor threshing TRAC in ha/hr was calculated from field observations, Appendix A9, and assumed to be uniform in the model. Tractor threshing was performed after all the cut stalk was transported. The area remaining to be threshed on day N, taken as ATRT in ha, was initially equal to the total area transported, ATR.

The area to be threshed ATRT by a tractor at a given time T was,

$$ATRT(T)=ATRT(0)-\int_0^T TRACdt \qquad (5.41)$$

or for time increment DT

ATRT=ATRT-TRAC*DT

The area threshed by tractor TATRT in ha, for a given time T was,

$$TATRT(T)=TATRT(0)+\int_0^T TRACdt \qquad (5.42)$$

and for increments of DT

TATRT=TATRT+TRAC*DT

If ATRT>0.0 and T>8, threshing was continued on N+1, on the condition that R=0.0. If R=1, threshing was repeatedly postponed until R=0.0. When ATRT<0.0 and T<8, cutting bundling, transport and tractor threshing were completed, Figure 5.11

d) Mechanical Threshing

Mechanical threshing was not common and seen mainly in commercial and research farms. The machine, if portable, may be taken to the field and used simultaneously with the bundling and transport operations, similar to the pedal threshing. The model assumed that the thresher was kept at a central location and the cut stalk transported to the threshing area before threshing. The area to be threshed AMT in ha was initially equal to the total area transported, ATR on day N.

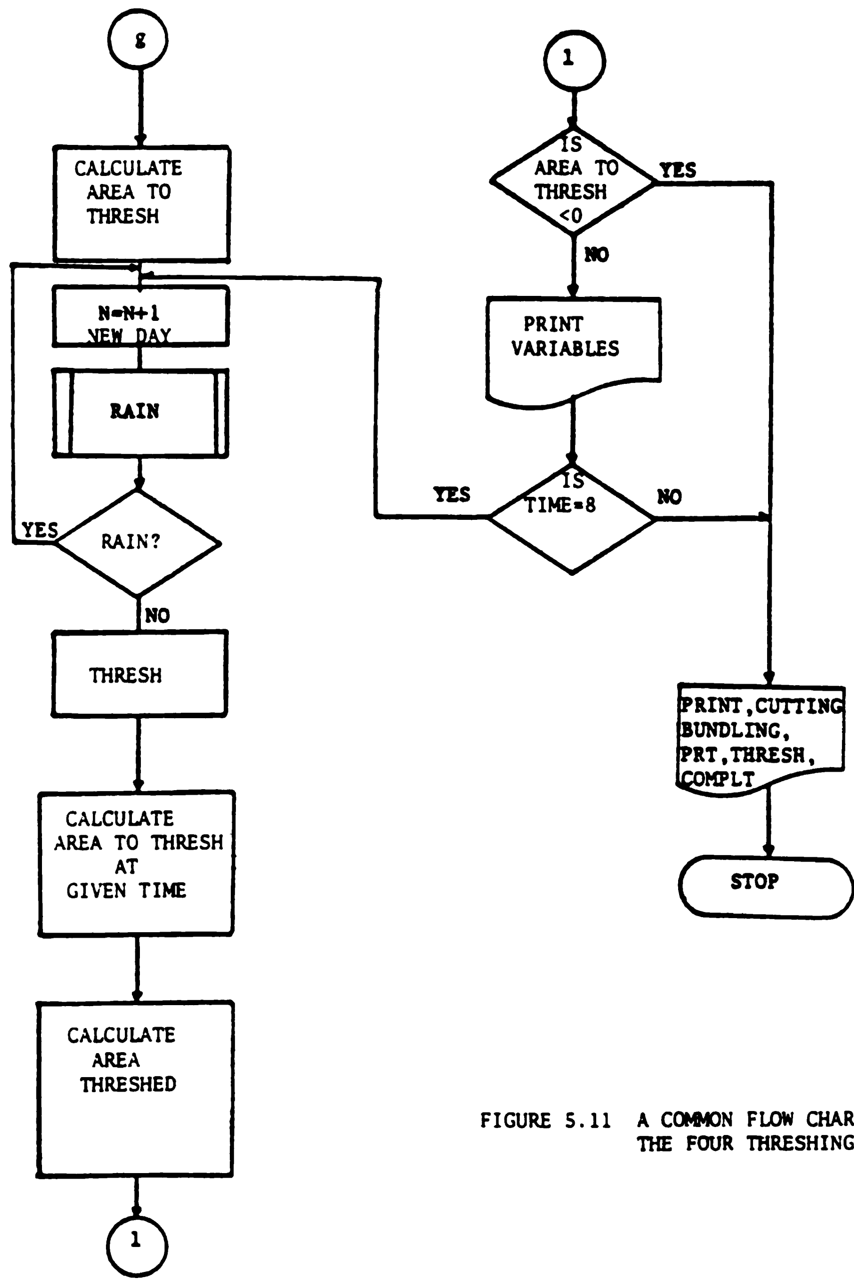


FIGURE 5.11 A COMMON FLOW CHART FOR THE FOUR THRESHING MODELS

The rate of mechanical threshing varied, depending on the capacity of the machine. Field observations made on an Iseki thresher were used in the model as the mechanical threshing rate TM in ha/hr. The threshing rate was assumed to be uniform throughout the operation.

The area to be mechanically threshed, AMT for a given time T was,

$$AMT(T)=AMT(0)-\int_0^T TMdt \tag{5.43}$$

or for increments of DT, by Euler integration

AMT=AMT-TM*DT

The area threshed by machine at a time T was represented by equation (5.44).

$$AMCHT(T)=AMCHT(0)+\int_0^T TMdt \tag{5.44}$$

or for time increments DT

AMCHT=AMCHT+TM*DT

An advantage of the mechanical thresher was that it could be operated if R=1, provided that a shelter was available if it rained. The model assumed that the thresher was housed in a farm shed and threshing was performed irrespective of the weather conditions. If AMT>0.0 and T>8, threshing was incomplete and continued on N+1 irrespective of whether R=1 or R=0.0. When AMT<0.0 and T<8, cutting, bundling and threshing were completed on day N_j, Figure 5.11, (which, however, shows the influence of R on the threshing operation).

The in-field post production process is complete when cutting, bundling, transport and threshing operations are finished. A total grain loss count, TOTL made by summing up all losses in the post production system, equation (5.45).

$$TOTL=PHVT+PSVT+BRDT+BNDLT+TRLT \tag{5.45}$$

After completing the in-field operations for the given land area, the model returned to cut a similar area at I=20 or I=i+4 until I=40, Figure 5.2

The percentage of broken grain was calculated at the beginning of every cutting operation using equations 4.44 to 4.63, depending on the variety tested. This value was used to determine the effects of harvest date and threshing method on the final output of rice.

The average grain moisture percentage was calculated before each cutting, bundling and transport operation, using equations 4.2 to 4.6, depending on the variety tested.

CHAPTER VI

SIMULATION RESULTS AND DISCUSSION

The simulation program was run on an IBM 370/158 computer, situated at the University of Hawaii, Manoa Campus, in Honolulu, Hawaii. The printout of the main program, subroutine RAIN, subroutine LABOR and subroutine FNL are illustrated in Appendices A10, A4, A2 and A2 respectively.

6.1 Inputs to the Model.

The variable RLAND was the area of land in ha cultivated with a known variety. The model simulated the cutting, bundling, transport and threshing operations involved in harvesting the given area RLAND. An area of 0.94 hectares was used as an input to test the model.

BG. 11-11 was used as the variety cultivated on RLAND. BG. 11-11 was seen to lodge after maturity, influenced by climatic conditions (Chapter IV). However, since BG. 11-11 was resistant to lodging but did exhibit lodging in certain fields, a lodging factor RLODG=0.25 was used in the model. This signified that 25 percent of the cultivated plants in RLAND lodged at cutting and therefore affected the cutting operation. RLODG would vary depending on the variety cultivated. For instance, H-4, which is very susceptible to lodging, would be given a factor of .85 to .90, indicating 85 to 90 percent lodging at time of cutting.

Family labor, LABF varied according to the farm families cultivating the land. Very often the wife and older children of a farmer join in the harvesting operations. The model is equipped to supplement the labor generated by subroutine LABOR, with the input LABF variable.

The rates of cutting, bundling and threshing are variable inputs to the model. The rates, RH, BR, TRAC, TM, TPT and TB for cutting, bundling, tractor, machine, pedal and buffalo threshing respectively are based on observations made on the field. These values could, however, be varied depending on the areas and time of operations.

The transport rate is calculated by the input variables X, D and B as given in equation (5.20). The average distance to the threshing floor D, could vary from one farm to another. Similarly, the speed of a man carrying the stalk could vary on the area and the labor used for transport. The area of stalk going into a bundle for head carrying B varies on the labor usage. Children tend to carry less than an adult and therefore B varies depending on the available labor.

The number of pairs of buffalos used in buffalo threshing is an input variable and depends on the availability of buffalos at threshing time as well as the land area to be harvested. A larger harvested land area would need additional pairs of buffalos to perform the operation faster.

6.2. Model Output.

The cutting operation of BG 11-11 was simulated every four days beginning on the 16th day and ending on the 40th day after 50 percent heading. The results of the simulation using a pedal drum for threshing are as follows.

Harvest on the 16th Day.

A total of 11 days were used to complete all operations. Cutting, bundling and transport were performed on the first four days while the threshing operation took 7 days to complete. Of the 7 days, two were rainy days on which the threshing operation was not performed. The resulting harvesting schedule is given in Table 6.1. The percentage sunchecks increased from 23.21 percent on the first day (16th day) to 26.37 percent on the second day, at which time the cutting operation was completed. Figure 6.1 represents the land area harvested, bundled, transported and threshed on each operation day. Figure 6.2 illustrates the available labor for each operation, while Figure 6.3 illustrates the losses in kg in the post production operations when harvested on the 16th day after 50 percent heading. The average moisture content and the broken grain percentage on the 16th day after 50 percent heading were calculated as 23.54 and 25.38 percent respectively.

Table 6.1: Harvesting Schedule for Harvest on 16th Day

Day	1	2	3	4	5	6	7	8	9	10	11
Cutting and Field Drying	*	*									
Transport and Bundling of Cut Stalk (DH)											
			Rain	Rain	Rain			Rain			
Transport and Bundling			*	*							
Threshing						*	*		*	*	*
Transport and Threshing											

<u>Harvest on the 20th Day</u>.

A total of 12 days were used to complete the harvesting operations. No operations were performed on the first four days due to rain. The stalk was harvested the 24th day and completed on the first hour of the 25th day using 8 labor units. The resulting harvesting schedule is given in Table 6.2. The percentage sunchecks increased from 35.86 on the 20th day to 51.66 on the 25th day when cutting was completed. Figure 6.4 represents the land area harvested, bundled, transported and threshed on each operation day. On the 7th day, the cut stalk was transported and threshed on the field. The remaining stalk was transported on the 8th day on which rain occurred, and then threshed from day 9 to

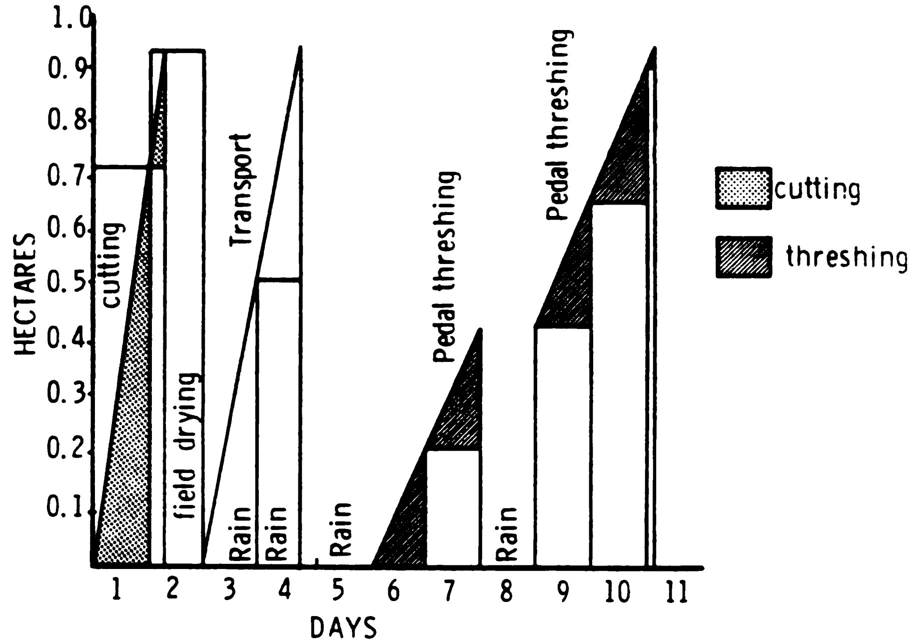


Figure 6.1 Areas Harvested Per Working Day. Cutting on 16th Day after 50% Heading

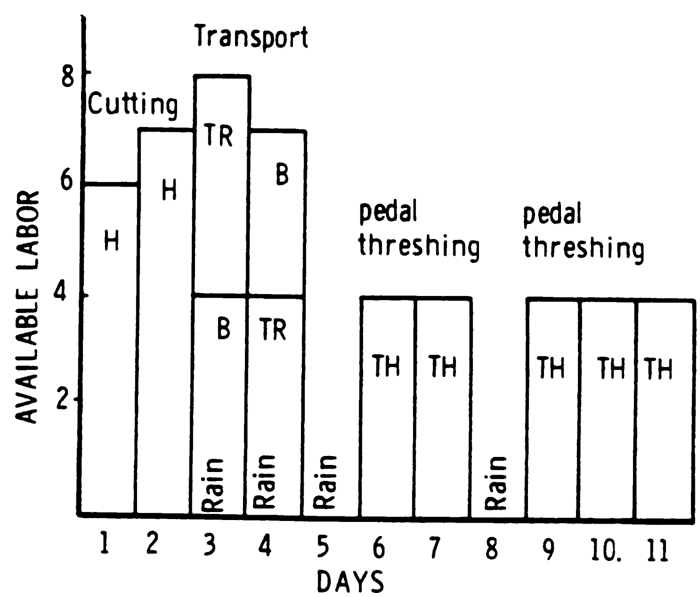


Figure 6.2 Available Labor for the Harvesting Operations, Cutting on 16th Day

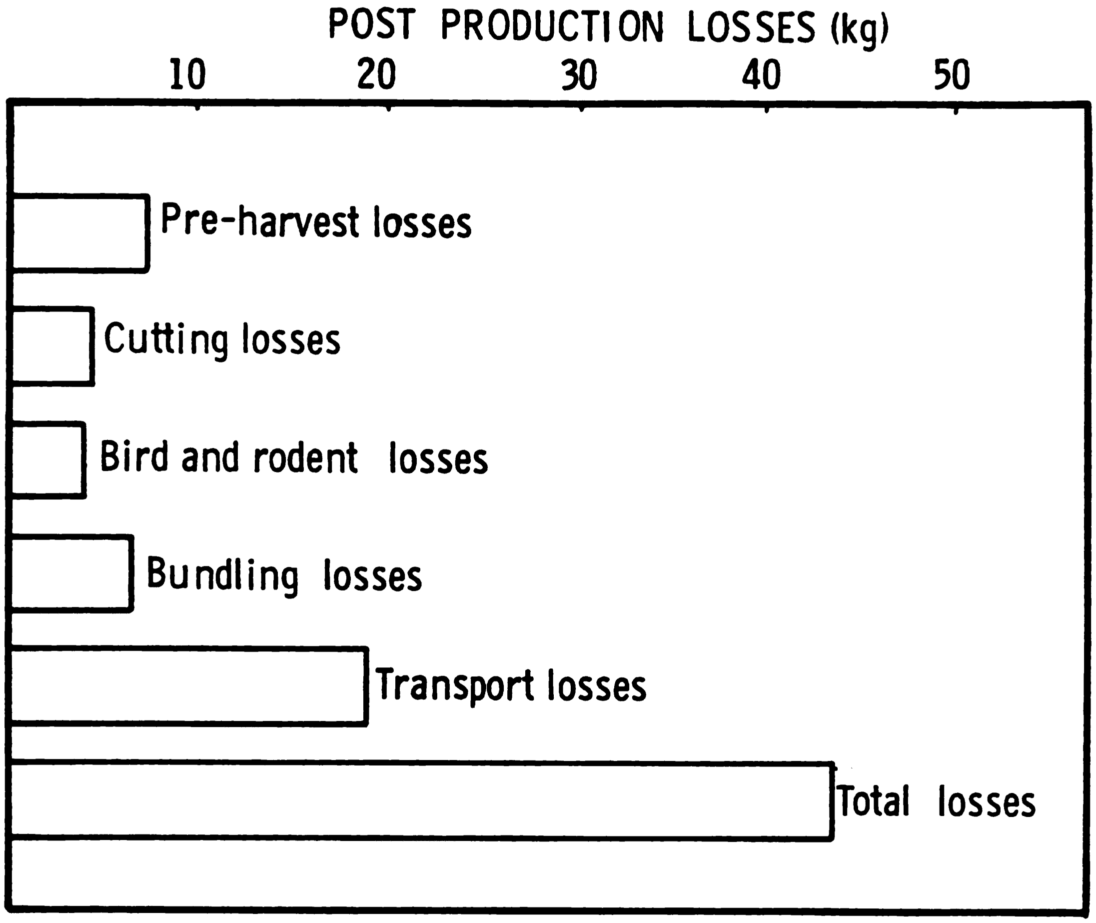


Figure 6.3 Losses in the Post Production Operations When Harvested at 16 Days after Heading (kg)

Table 6.2: Harvesting Schedule for Harvests on the 20th Day after 50 Percent Heading

Day	1	2	3	4	5	6	7	8	9	10	11	12
Cutting and Field Drying	Rain	Rain	Rain	Rain	*	*						
Transport and Bundling of Stalk (DH)												
Transport and Bundling								Rain *				
Transport and Threshing							*					
Threshing									*	*	*	*

day 12. Figure 6.5 illustrates the available labor for each operation, while the grain losses of the post production operations are illustrated in Figure 6.6. The average moisture content and broken grain percentage on the 20th day after 50 percent heading were calculated as 23.69 and 21.35 percent respectively.

Harvest on the 24th Day.

All operations were completed in 7 days. The fifth day was a rainy day on which the harvested stalk remaining to be threshed were transported to the threshing floor. Table 6.3

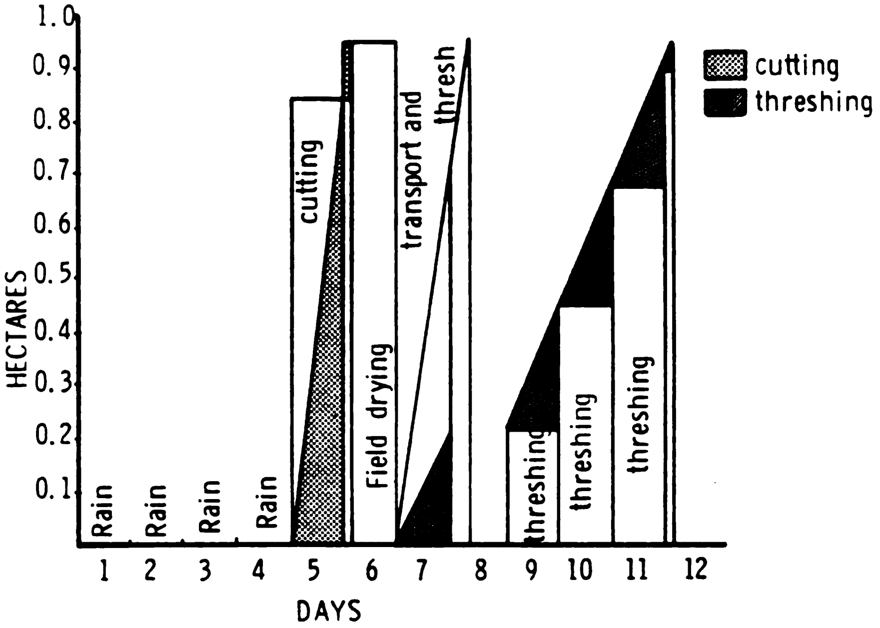


Figure 6.4 Areas Harvested Per Working Day.
Cutting on 20th Day After 50% Heading

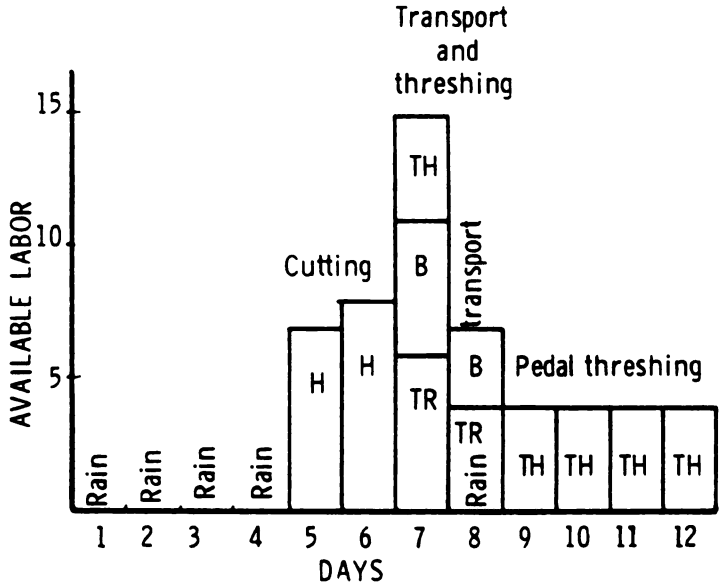


Figure 6.5 Available Labor for the Harvesting Operations.
Cutting on the 20th Day

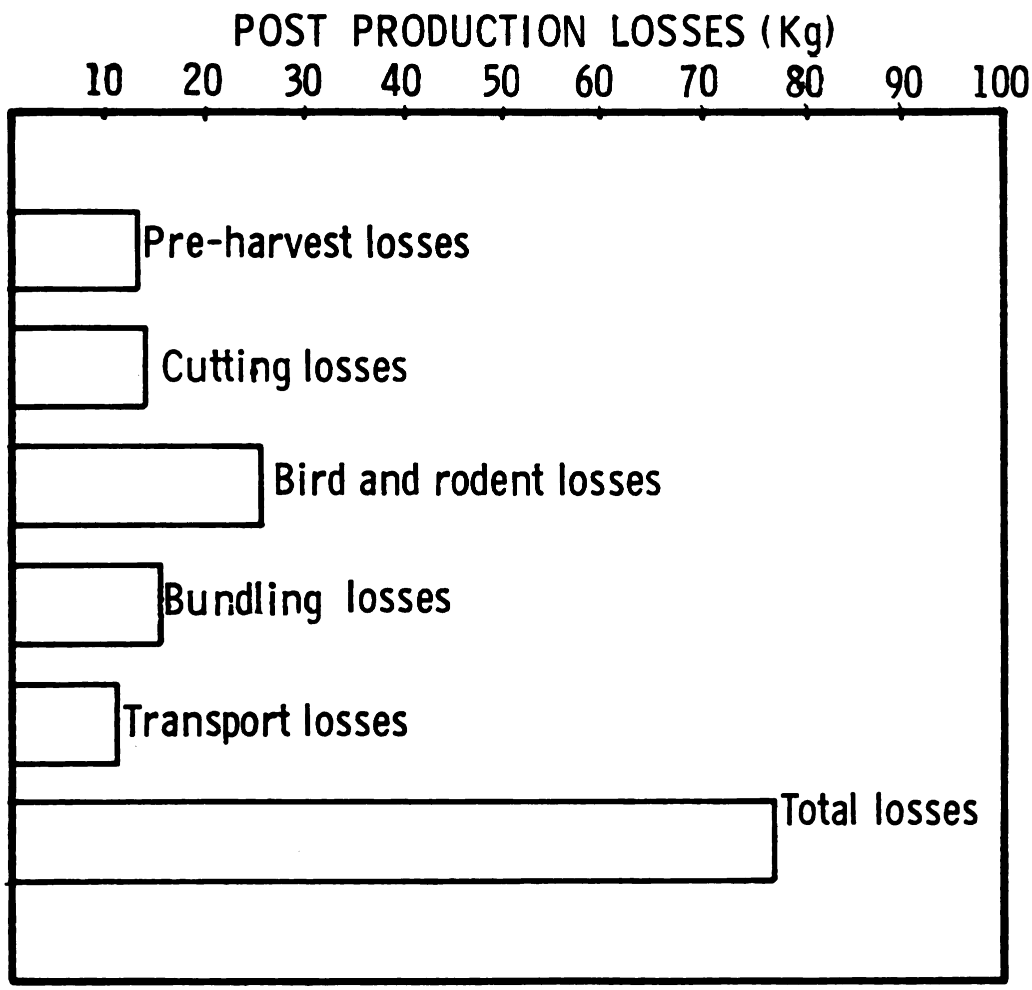


Figure 6.6 Losses in the Post Production Operations When Harvested at 20 days after 50% Heading (kg)

Table 6.3: Harvesting Schedule for Harvest on 24th Day

Day	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Cutting and Field Drying	*														
Transport and Bundling of Cut Stalk (DH)								complete							
Transport and Bundling					Rain *										
Transport and Threshing		*	*	*											
Threshing						*	*								

illustrates the resulting harvesting schedule when the stalks were cut on the 24th day after 50 percent heading. The cutting operation was completed on the 7th hour of the first day using seven units of labor. The percentage sun-checks at the time of cutting was 48.5. The cut stalk was transported and threshed on the field from the 2nd to the 4th day. The remaining stalk was transported and threshed on the 6th and 7th day, Figure 6.7. The labor availability and distribution for different post production operations is illustrated in Figure 6.8. Grain losses in the harvesting operations when cutting begins on the 24th day after

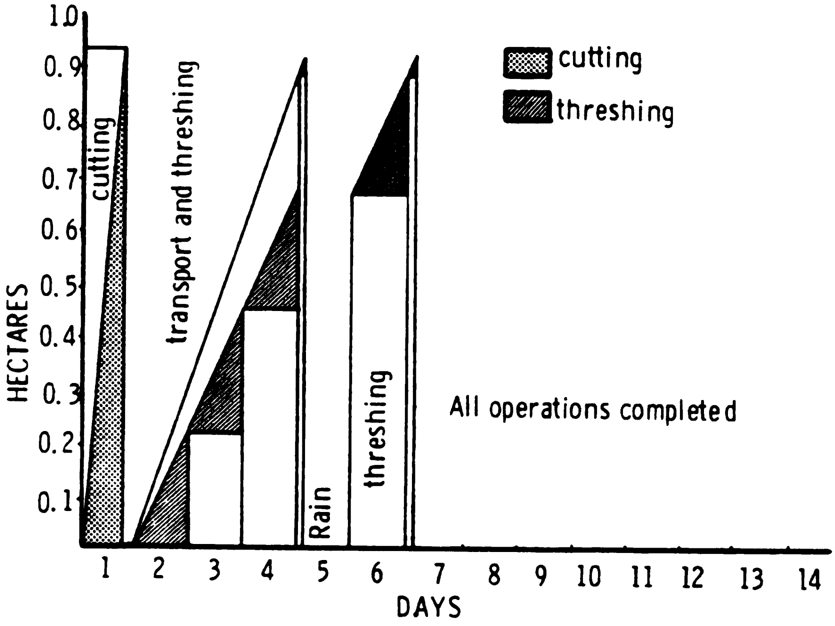


Figure 6.7 Areas Harvested Per Working Day. Cutting on 24th Day after 50% Heading.

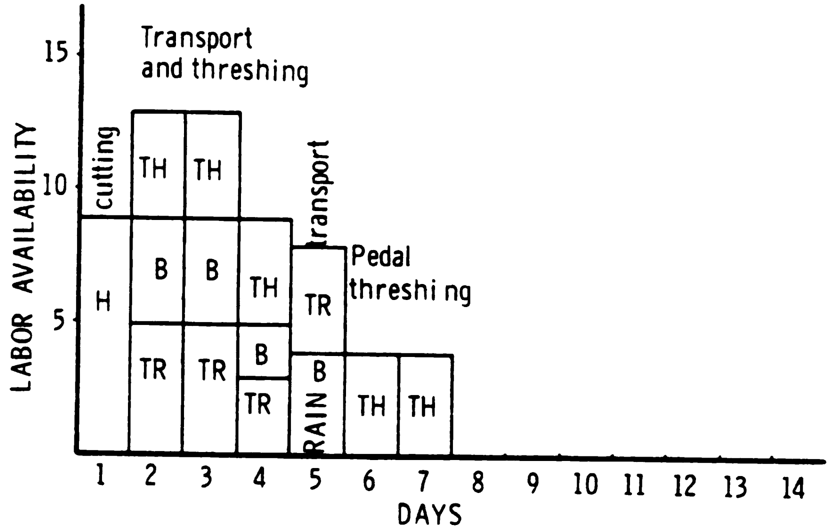


Figure 6.8 Available Labor for the Harvesting Operations. Cutting on the 24th Day

50 percent heading is illustrated in Figure 6.9. The average grain moisture and broken grain on the 24th day after 50 percent heading were calculated as 23.42 and 19.07 respectively.

Harvesting on the 28th Day.

Table 6.4 represents the harvesting schedule when the stalk is harvested 28 days after 50 percent heading. No rainy days were experienced, Figure 6.10. The cutting operation was completed on the 7th hour of the first day using 9 labor units. The cut stalks were transported and threshed on the field from the 2nd day to the 6th day. The transport and threshing operation was completed on the first one and a quarter hour of the 6th day. The percentage of sunchecks on the 28th day was calculated as 61.14 percent. Figure 6.11 illustrates the labor availability and distribution during the six day harvesting operation. The grain losses associated with the different harvesting operations are illustrated in Figure 6.12. The average grain moisture and percentage of broken grains were calculated as 22.73 and 18.54 respectively.

Harvesting on the 32nd Day.

A total of nine working days were used to complete the harvesting operations, Table 6.5. The stalk was cut on the first day using seven labor units. The cutting operation

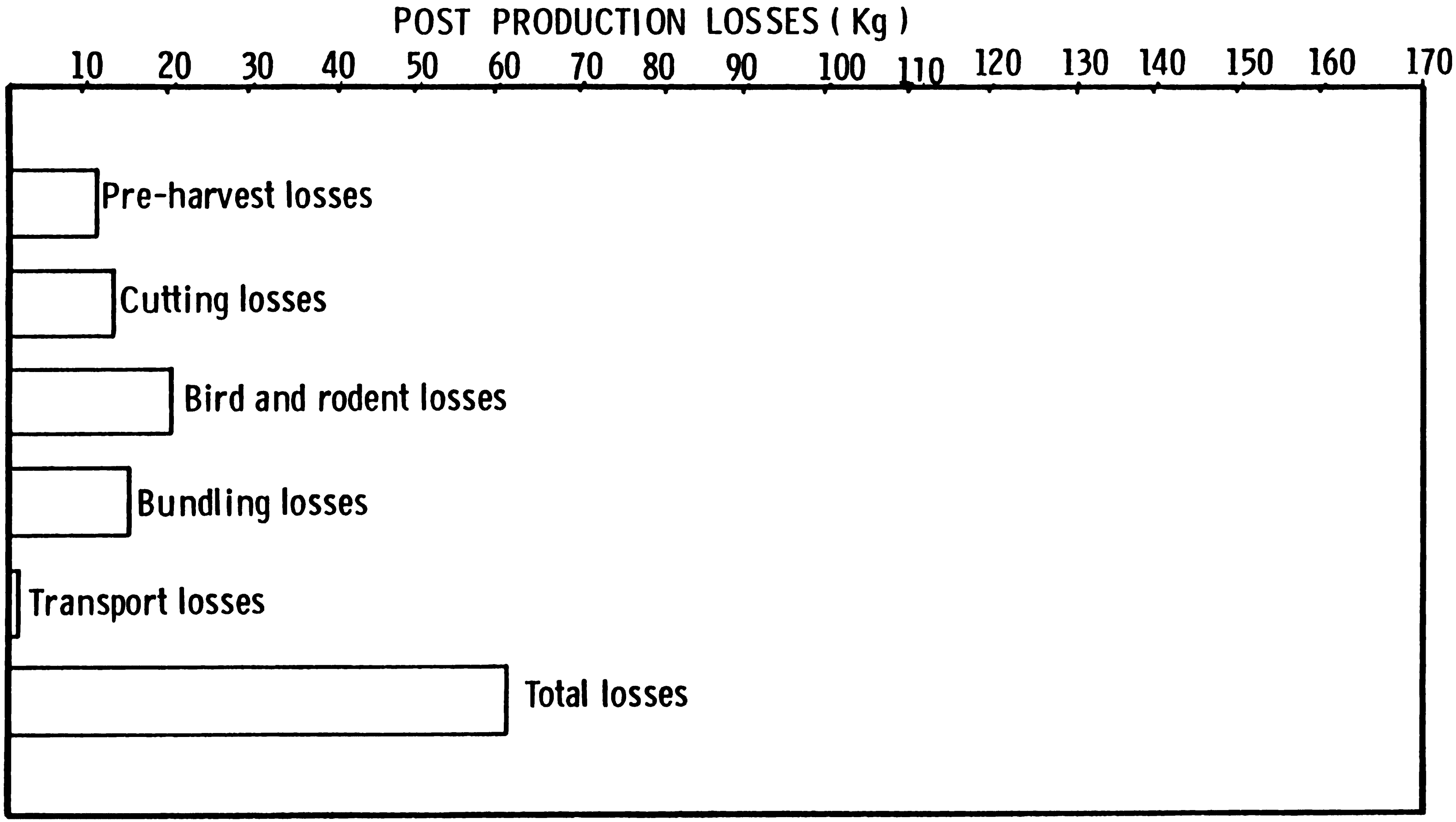


Figure 6.9 Losses in Post Production Operations When Harvested at 24 Days After 50% Heading (kg)

Table 6.4: Harvesting Schedule for Harvest on the 28th Day

Day	1	2	3	4	5	6		7	8	9	10	11	12	13	14
Cutting and Field Drying	*														
Transport and Bundling of Cut Stalk (DH)							complete								
Transport and Bundling															
Transport and Threshing		*	*	*	*	*									
Threshing															

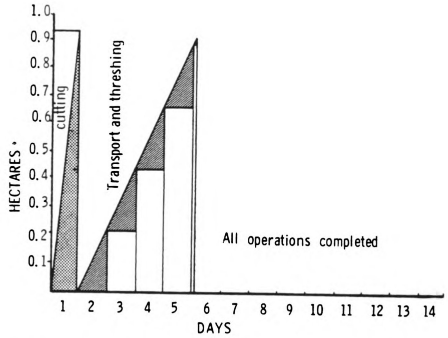


Figure 6.10 Areas Harvested Per Working Day, Cutting on the 28th Day after 50% Heading

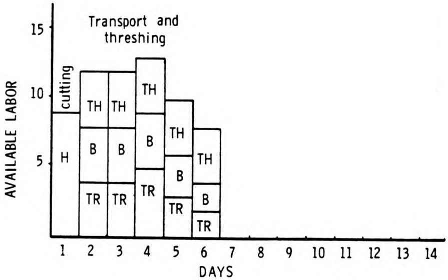


Figure 6.11 Available Labor for the Harvesting Operations. Cutting on the 28th Day

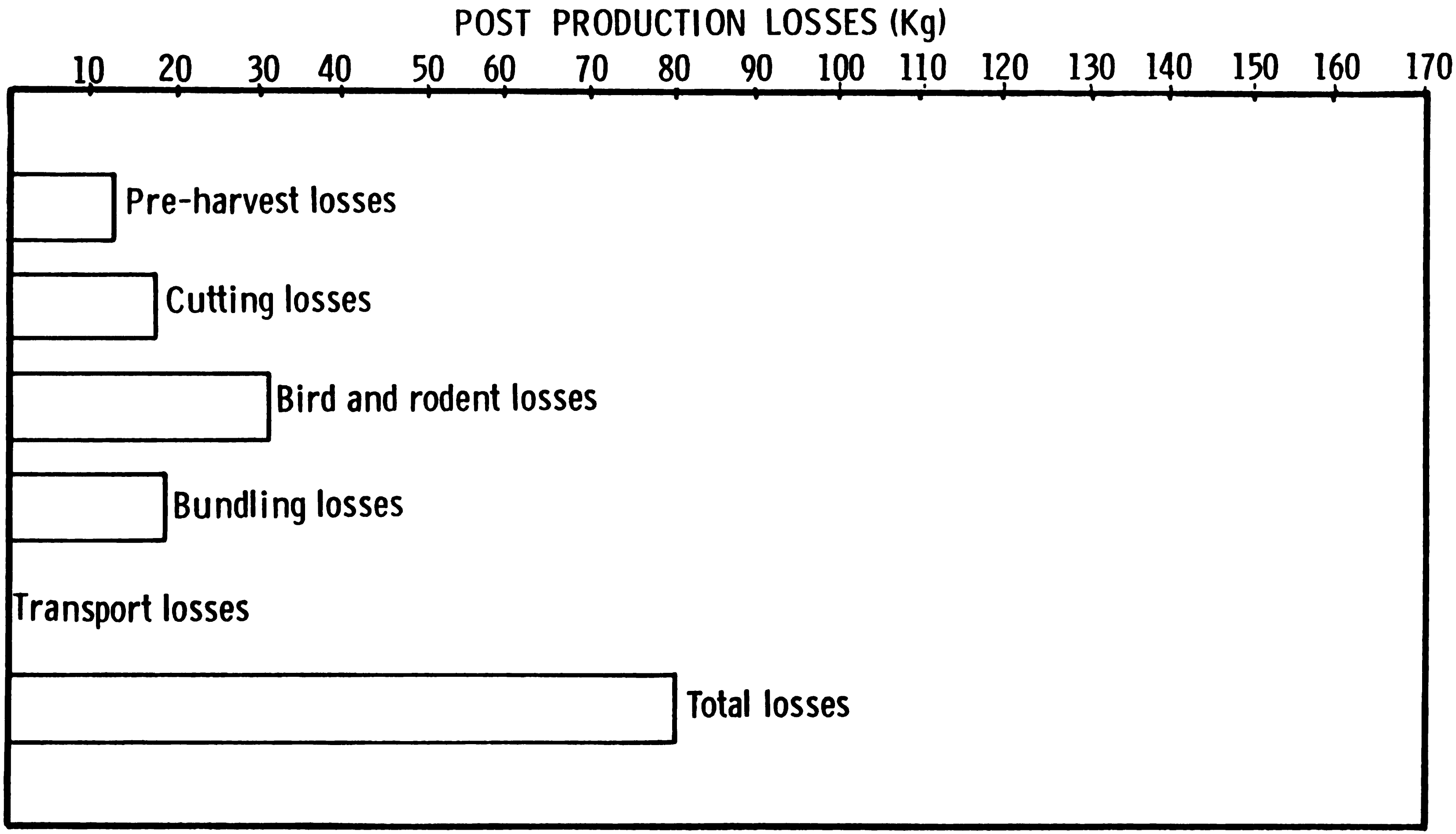


Figure 6.12 Losses in the Post Production Operations When Harvested at 28 days After 50% Heading

Table 6.5: Harvesting Schedule for Harvest on the 32nd Day

Day	1	2	3	4	5	6	7	8	9		10	11	12	13	14
Cutting and Field Drying	*			*											
Transport and Bundling of Cut Stalk (DH)		Rain *	Rain *							complete					
Transport and Bundling															
Transport and Threshing					*	*	*	*	*						
Threshing															

was incomplete, but could not be performed on the next two days due to rain. The cut stalk (DH) was transported on the 2nd day and the transport operation completed on the 5th hour of the 3rd day on which rain occurred, Figure 6.13. The stalk remaining on the field was cut and the cutting operation completed on the first hour of the 4th day. The percentage sunchecks on the 32nd day was 73.79 and on the day cutting was completed, 83.27. The cut stalk was left on the field to dry overnight. Transport and field threshing was performed from the 5th day and completed on the first one and three quarter hour on the 9th day. The labor

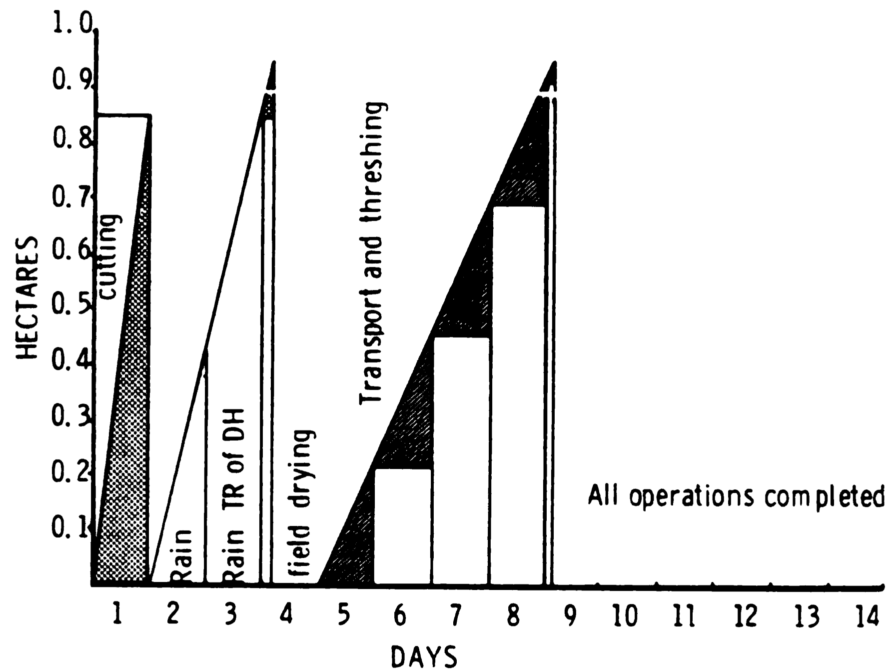


Figure 6.13 Areas Harvested Per Working Day. Cutting on the 32nd Day after 50% Heading.

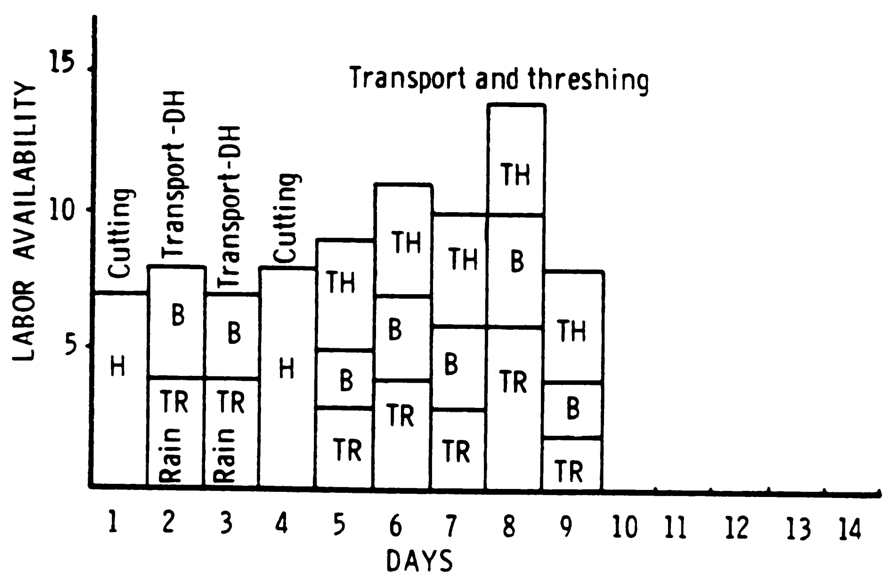


Figure 6.14 Available Labor for the Harvesting Operations, Cutting on the 32nd Day.

availability and distribution is illustrated in Figure 6.14. The average grain moisture and percentage of broken grains due to pedal threshing were calculated as 21.62 and 19.76 percent respectively. Figure 6.15 illustrates the grain losses in the different harvesting operations when harvested on the 32nd day after 50 percent heading.

Harvesting on the 36th Day.

A total of six days were used to complete the different operations, Table 6.6. The stalk was cut and the operation completed on the 7th hour of the first operating day, Figure 6.16. Transport and field threshing was performed from the 2nd and completed on the first hour of the sixth day. The percentage of sunchecks on the 36th day was calculated as 86.43 percent. Figure 6.17 illustrates the labor availability and distribution during the harvesting operations. The grain losses for the different operations is illustrated in Figure 6.18. The average grain moisture percentage and percentage broken grains when harvested on the 36th day were calculated as 20.08 and 22.73 percent respectively.

Harvesting on the 40th Day.

Table 6.7 illustrates the harvesting schedule when the stalks were cut on the 40th day after 50 percent heading. Stalks were cut on the 40th day when the average grain

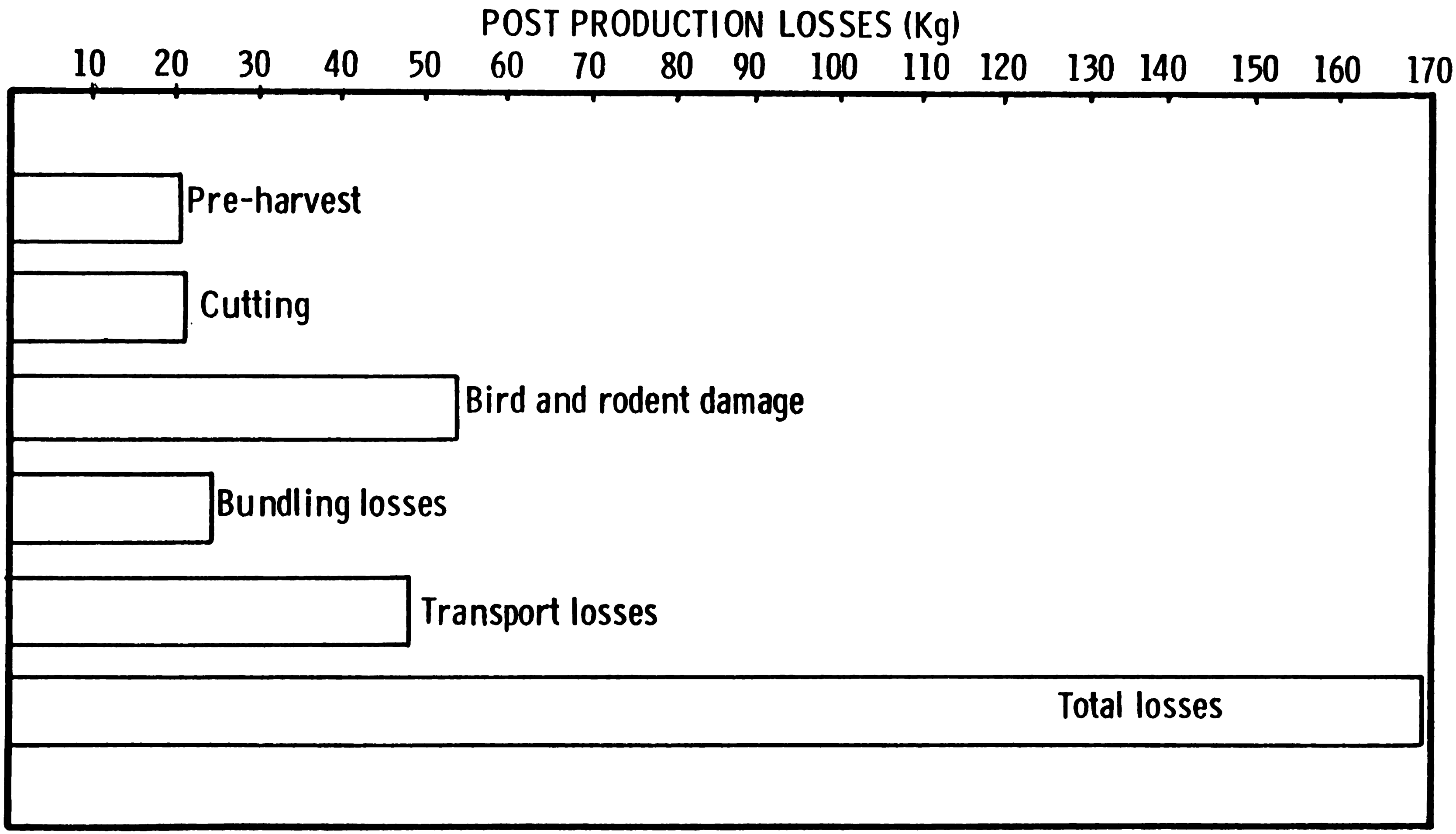


Figure 6.15 Losses in the Post Production Operations When Harvested at 32 Days After 50% Heading (kg)

Table 6.6: Harvesting Schedule for Harvests on the 36th Day.

Day	1	2	3	4	5	6		7	8	9	10	11	12	13	14
Cutting and Field Drying	*														
Transport and Bundling of Cut Stalk (DH)							complete								
Transport and Bundling															
Transport and Threshing		*	*	*	*	*									
Threshing															

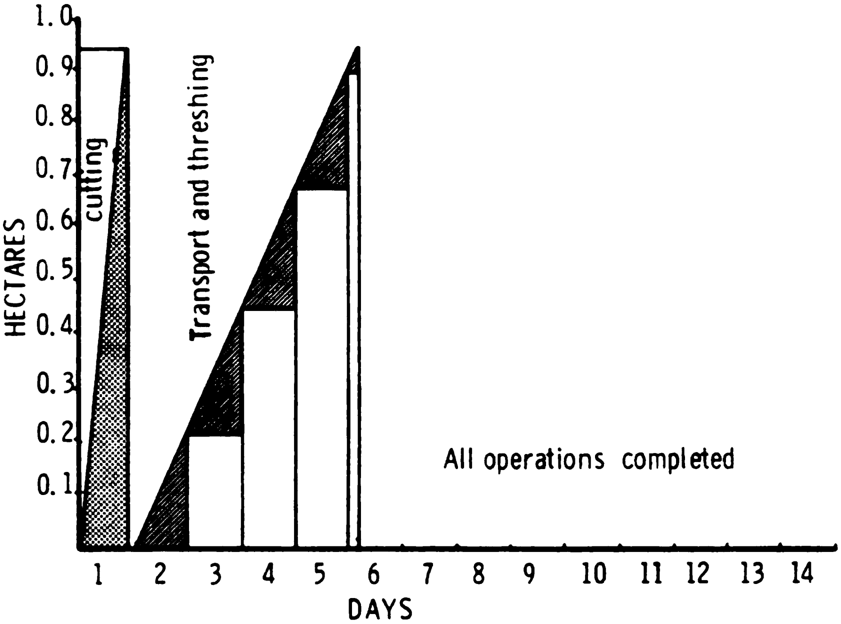


Figure 6.16 Areas Harvested Per Working Day. Cutting on the 36th Day after 50% Heading

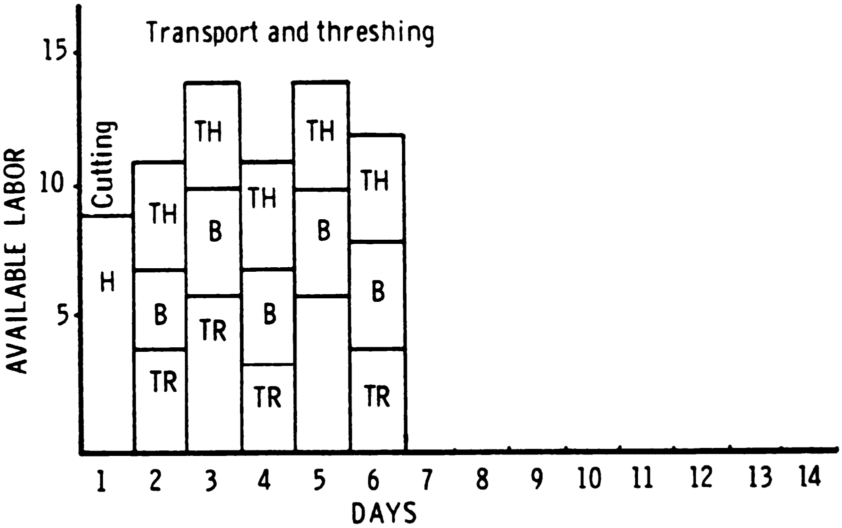


Figure 6.17 Available Labor for the Harvesting Operations. Cutting on the 36th Day

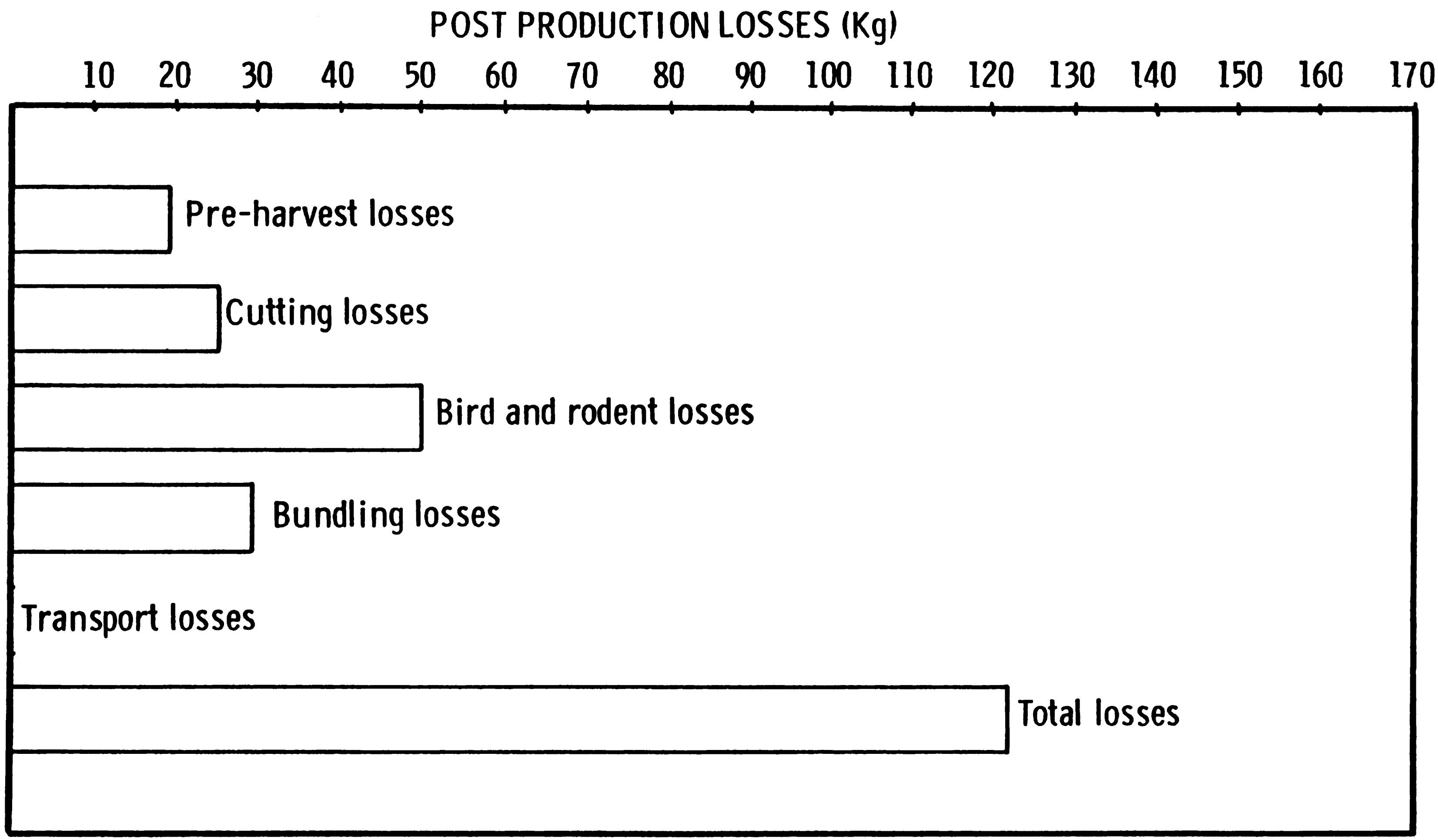


Figure 6.18 Losses in the Post Production Operations When Harvested at 36 Days After 50% Heading

Table 6.7: Harvesting Schedule for Harvests on 40th Day.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cutting and Field Drying	*		Rain	Rain	Rain	Rain	Rain	Rain	*					
Transport and Bundling of Cut Stalk (DH)		Rain *												
Transport and Bundling														
Transport and Threshing										*	*	*	*	*
Threshing														

moisture content was 18.13 percent. Five units of labor were used in the cutting operation which was incomplete on the first day. Due to rain on the 2nd day, the cut stalk (DH) was transported using 6 labor units for transport and 5 labor units for the bundling operation. No operations were performed on the days 3 to 8 due to rain, Figure 6.19. The unharvested area was cut and the cutting operation completed on the 3rd hour of the 9th day. The cut stalk was field dried overnight. The cut stalk were transported and field threshed from day 10 and the operations were completed on the first hour of the 14th day. The percentage of

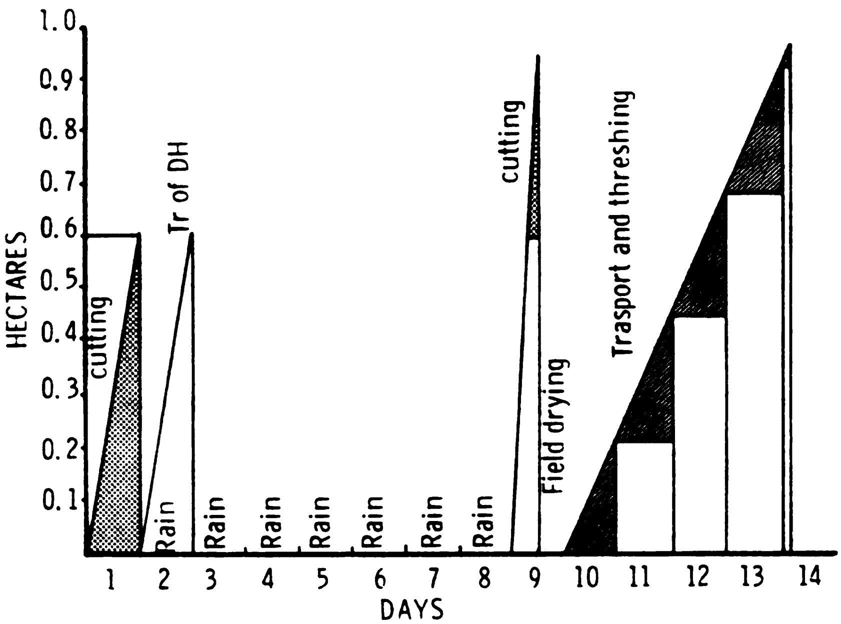


Figure 6.14 Areas Harvested Per Working Day. Cutting on the 40th Day After 50% Heading.

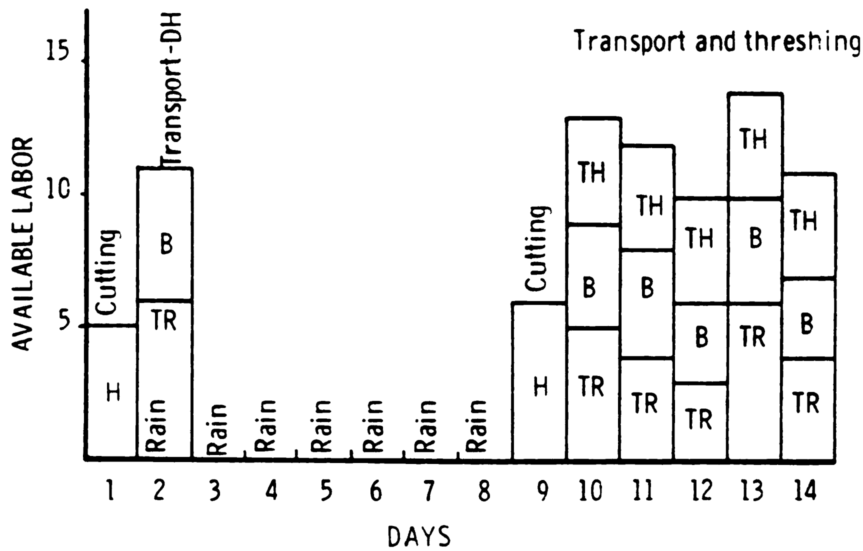


Figure 6.20 Labor Availability for the Harvesting Operations. Cutting on the 40th Day (kg)

sunchecks on the 40th day was calculated as 99.07 percent. The labor availability and distribution is illustrated in Figure 6.20, while the grain losses for the different harvesting operations are given in Figure 6.21. The percentage of broken grains on the 40th day was calculated as 27.45.

Similar results were obtained in simulating the harvesting operations using the tractor, machine and buffalo for threshing, (Appendices A11; A12 and A13). Figure 6.22 illustrates the simulated percentages of broken grain and average moisture content for the different harvest dates. Tractor and buffalo threshing had a higher percentage of broken grain than machine threshing and pedal threshing. A high force from the weight of the tractor and its wheels results in broken grains. Similarly, the weight and concentrated forces exerted by the hooves of the buffalos results in increased broken grain. The low threshing forces exerted by the pedal thresher resulted in a lower percentage of cracked grains. The percentage of broken grains in all threshing methods decreased from the 16th day and was at a minimum on the 28th day after 50 percent heading. The percentage of broken grains increased from the 28th day, indicating a loss of head rice at milling when the stalk was harvested beyond the maturity period. The percentage of sunchecks increased with delays in harvesting, Figure 6.23. An increase in sunchecks gives rise to a higher breakage at milling. An increase in sunchecks will also cause the grain

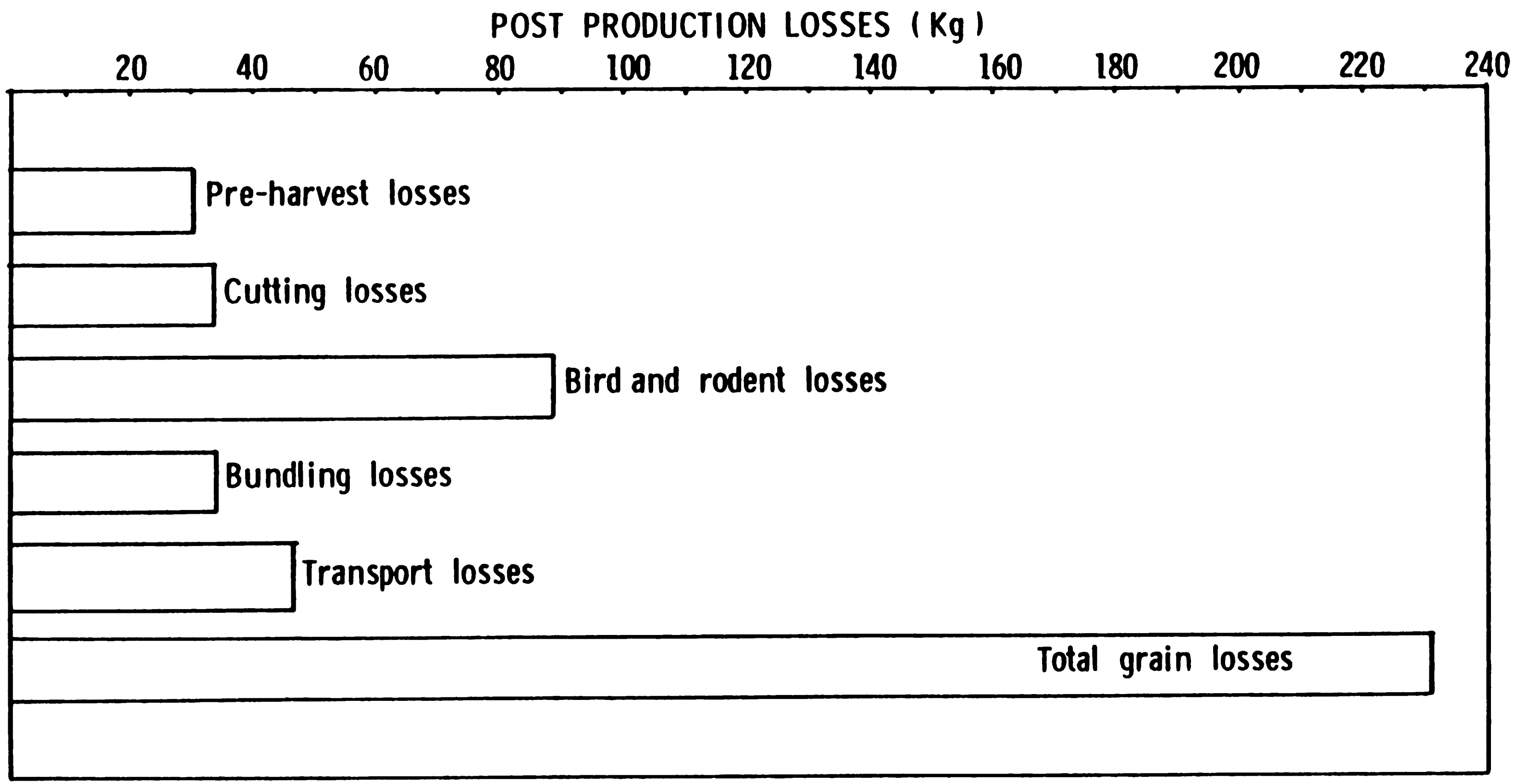


Figure 6.21 Losses in Post Production Operations. Harvesting at 40 Days After 50% Heading (kg)

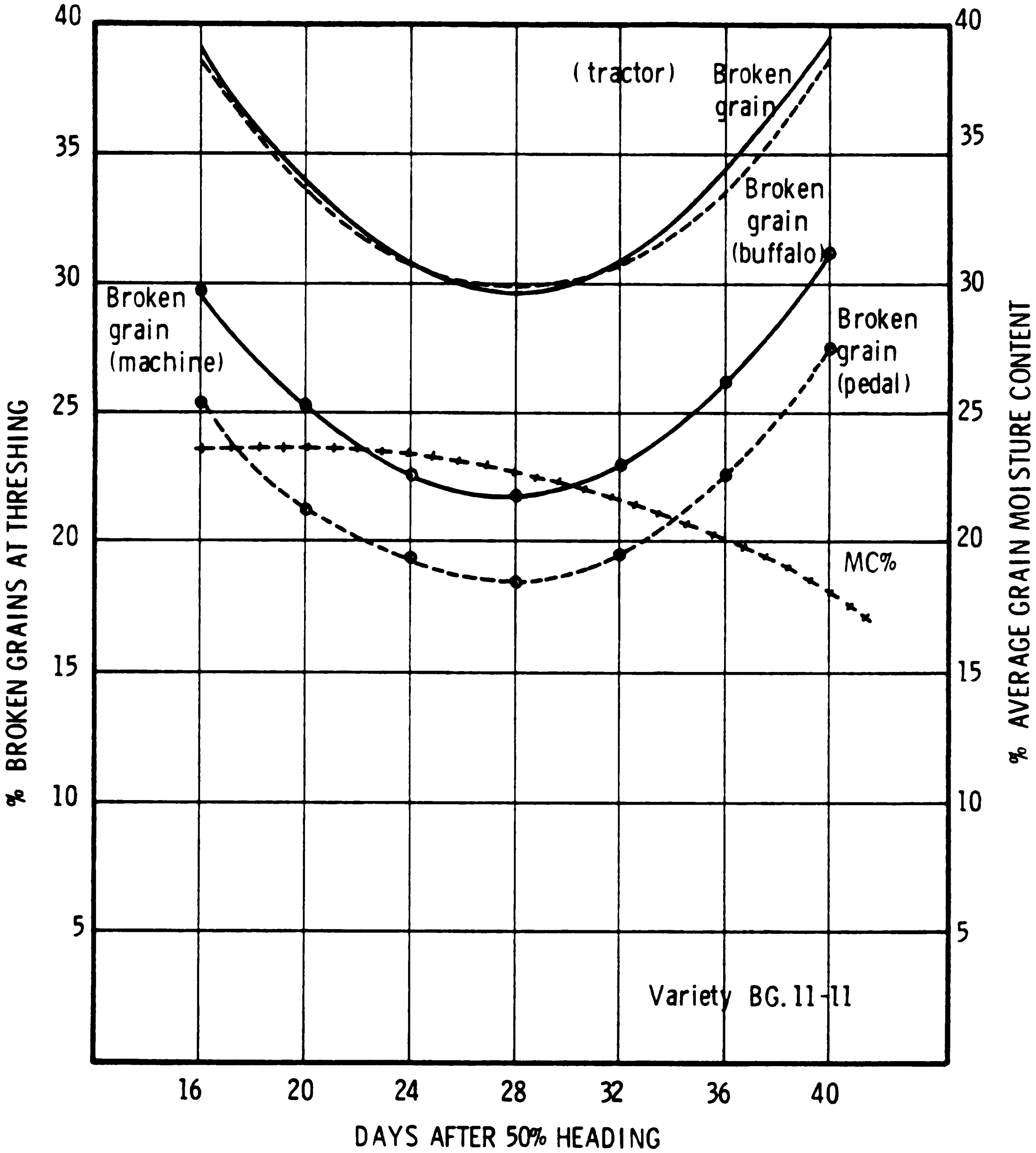


Figure 6.22 Simulated % Broken Grains and % Moisture Content at Different Harvesting Dates

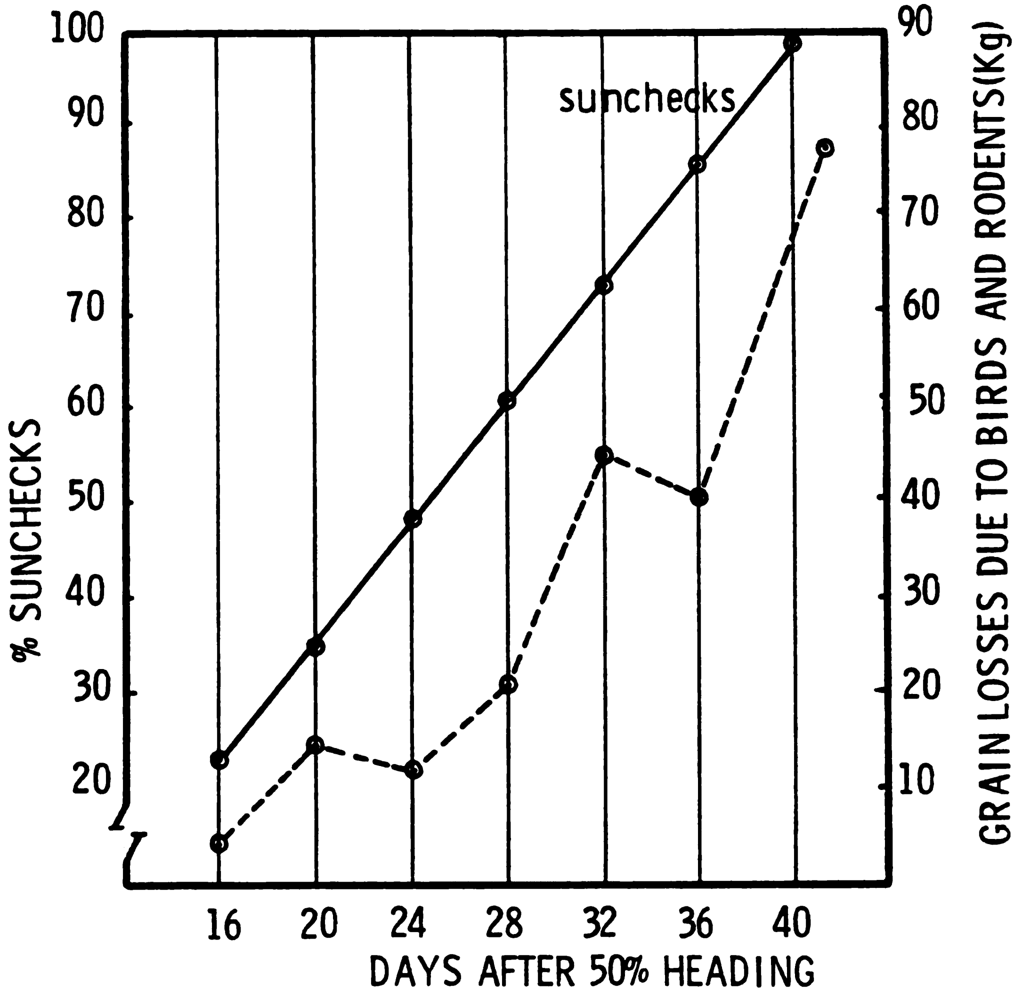


Figure 6.23 % Sunchecks and Grain Losses Due to Birds and Rodents at Different Harvesting Dates

to crack under the forces of threshing, thereby resulting in a higher percentage of broken grain. The lowest percentage of cracked grains were at around the 28th day. This indicated that for a lower percentage of broken grain, the stalk should be harvested between the 24th and 30th day after 50 percent heading.

Losses in grain in the cutting and bundling operations increased with the increase in maturity, Figure 6.24. With an increase in maturity grains tend to shatter easily and result in grain shedding at handling. Losses of grain due to birds and rodents as well as losses before cutting increased with maturity. Bird and rodent losses for the total area harvested on the 40th day was 88.58kg (sum of the 40th and 48th day). The model did not sum up bird and rodent losses if the harvest was repeatedly postponed due to rain. The repeatedly summed up loss values for an unharvested area would result in inflated grain losses for bird and rodent damage. The total grain loss before cutting on the 40th day was 30.46kg (sum of the 40th and 48th day).

The total labor use on the 20th, 24th and 36th day increased with the use of additional labor for bundling, transporting and field threshing simultaneously, Figure 6.25. The high labor use for the 32nd and 40th day is due to the additional labor utilized to transport the cut stalk DH, before the cutting operation was complete.

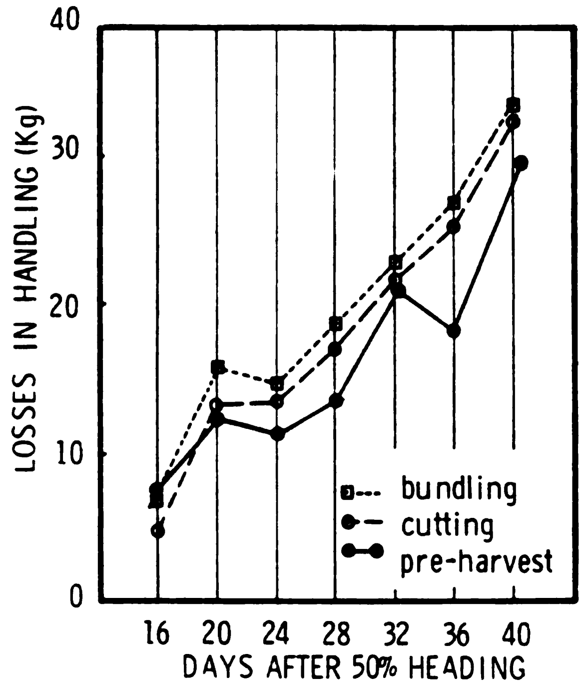


Figure 6.24 Simulated Handling Losses for Different Harvest Dates

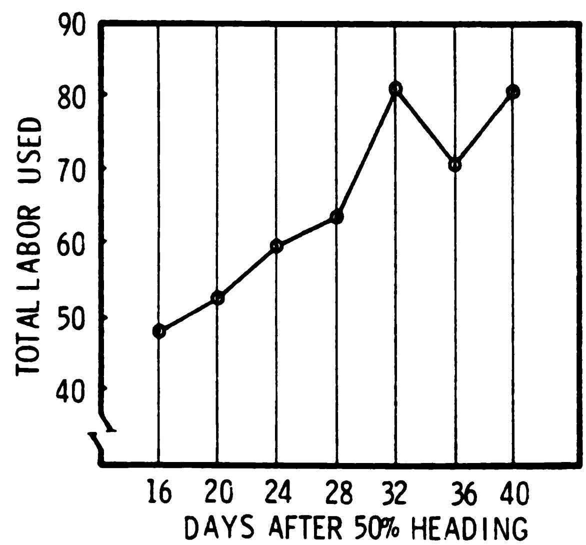


Figure 6.25 Simulated Total Labor Used at Different Harvest Dates

Figure 6.26 illustrates the losses due to transport of cut stalk from the field to the threshing floor for tractor, machine and buffalo threshing. Losses due to transport of stalk to the pedal thresher situated on the field is assumed in the model to be zero. The pedal thresher may be moved to areas where bundles are made, eliminating the need to transport these bundles. Losses from the transport of stalk to the threshing floor increased with an increase in maturity. Grain losses from transport using a pedal thresher on day 16 is explained by the transport of all cut stalk on day 3 and 4 when rain occurred, Figure 6.1. Field threshing was not performed in this harvesting period. Similarly, in Figure 6.4 cut stalk was transported on the 8th day. Field threshing was performed on all the stalk harvested 28 days and 36 days after 50 percent heading. Transport losses were therefore zero. The high transport losses on harvest days 32 and 40 are due to the transport of cut stalk DH, on days when rain occurred before completing the cutting operations, Figure 6.13 (days 2 and 3) and Figure 6.19 (day 2). The use of the pedal thresher on the field decreased the losses in grain in comparison to the need for stalk transport to facilitate tractor, buffalo and mechanical threshing.

The total grain loss in the in-field post production operations is illustrated in Figure 6.27. Grain losses in the simulation of the in-field post production systems

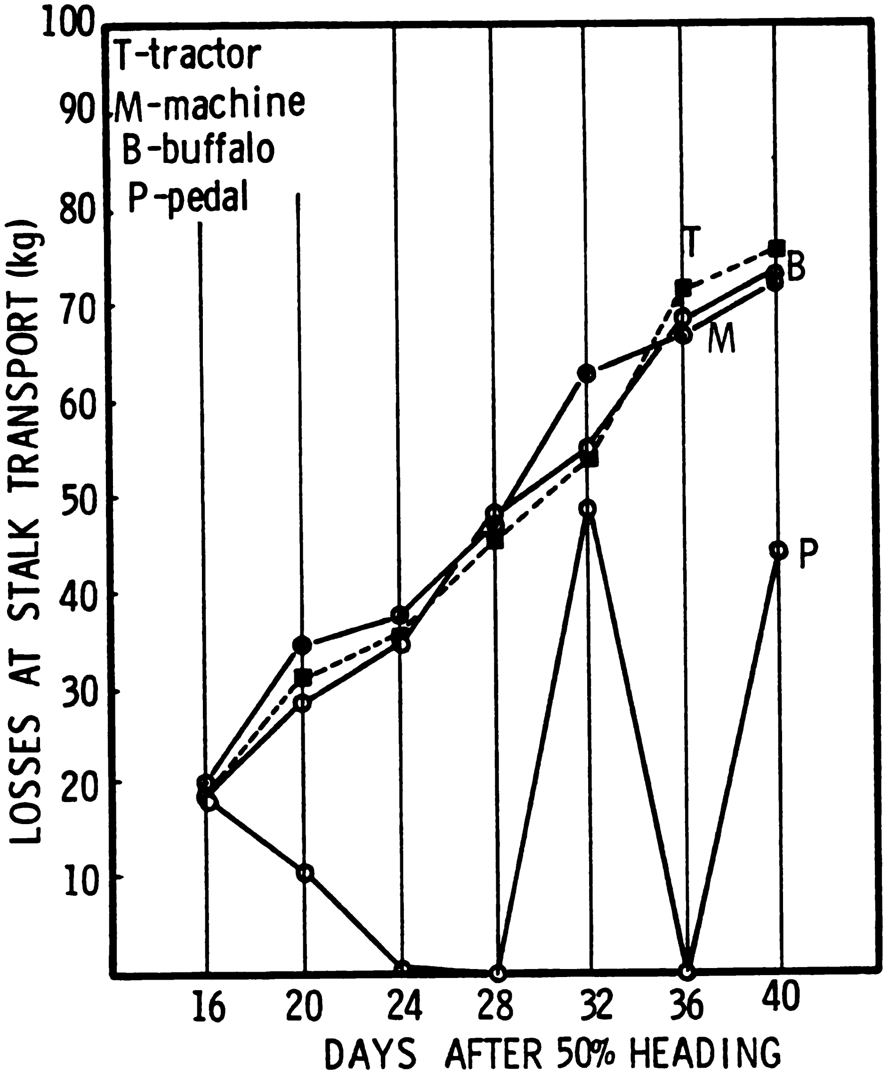


Figure 6.26 Simulated Losses at Transport in (kg)

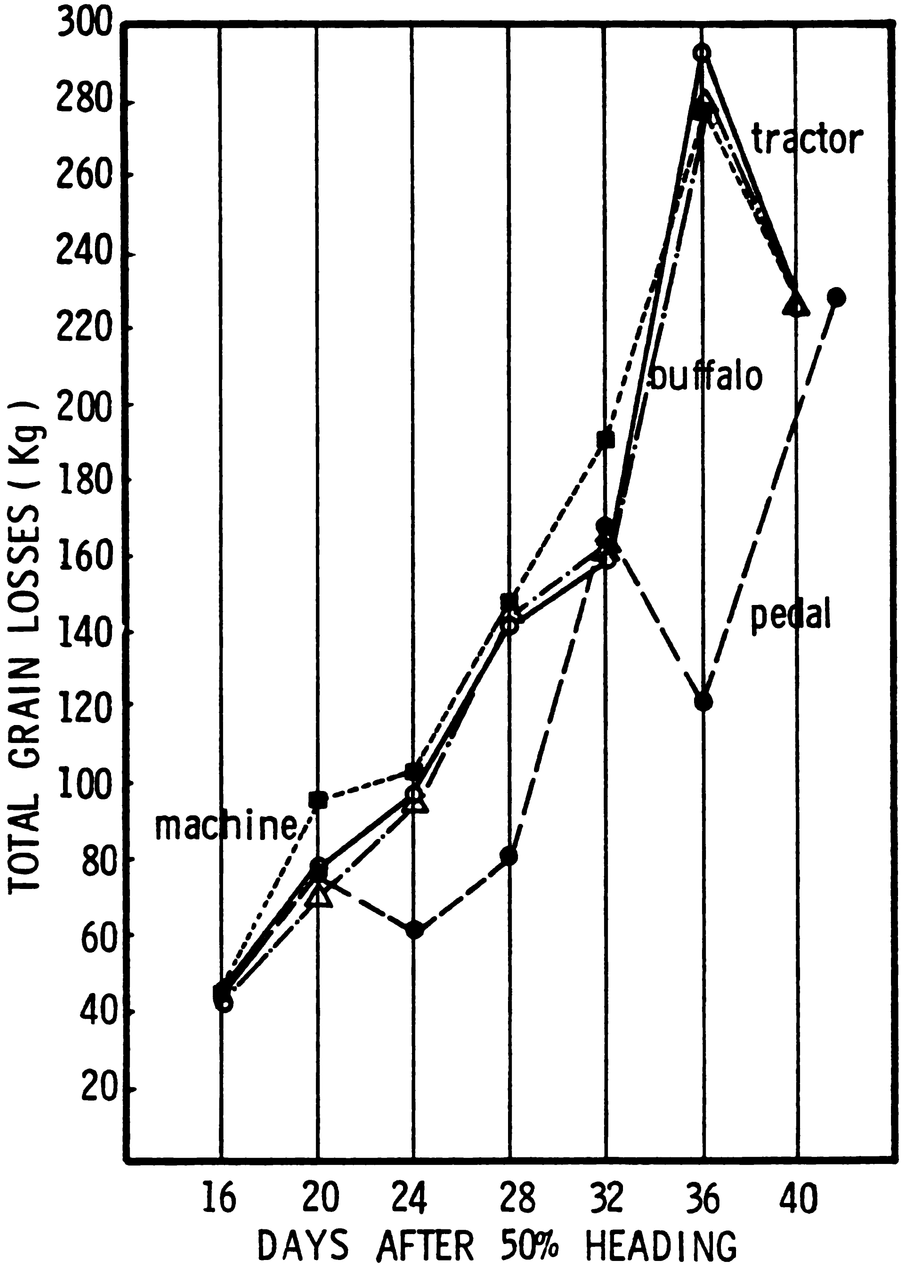


Figure 6.27 Simulated Total Grain Loss in the In-Field Post Production Operation

utilizing the tractor, machine or buffalo had a higher total grain loss than the system using a pedal thresher. A high loss on the 36th day for the systems using a threshing floor was due to delayed harvesting arising from the non-availability of labor and occurrence of rain on scheduled harvest dates, (Appendices A11; A12 and A13). The increase in losses in the system using the pedal thresher was influenced by weather when the cut stalk had to be transported.

The model illustrated the influence of rain on all operations from cutting to threshing. Rain was seen to affect the total operational procedure. Delays in harvest caused by rain increased the susceptibility of plants to bird and rodent damage as well as preharvest grain shattering. Rain delayed the harvest of stalk at the optimum cutting time, influencing grain losses due to handling as well as the percentage of broken grains at milling. Rain increased the total time period required to harvest and thresh a given area of land. A total of 14 days were used to harvest and thresh 0.94 hectares, Figure 6.19. Seven of the 14 days had rain, therefore restricting harvesting operations on six days and delaying the cutting operation by seven days. The same area of land was cut, transported and pedal threshed in six days when no rain occurred, Figures 6.10 and 6.16.

The complex interdependencies of weather, labor availability, harvest operations and animal damage influencing the losses in the grain were simulated using the in-field simulation model. Variations in the results could be obtained by changing the input variables and seed values of the random number generator (IMSL subroutine for IBM 370).

CHAPTER VII

RECOMMENDATIONS

The following recommendations are made based upon this research on rice post production losses and technology.

1. The rice paddy fields should be harvested between the 28th and 32nd days after 50 percent of the heading has occurred.
   a) Shattering losses, cracked kernels and bird and rodent losses can be reduced by as much as 30 kg/ha by harvesting at this most optimum time.
   b) Harvesting rice between 28 and 32 days after 50 percent heading produces grain paddy with 20 to 25 percent moisture content (wet basis). This comparatively high moisture content minimizes the stalk paddy handling losses, but increases and complicates the drying problems associated with both the stalk and grain paddy. The stalk paddy must be threshed at this high moisture content and then dried immediately.
2. Sickle cutting of the paddy stalk at the optimum harvesting time will continue to be the most viable means of cutting for some time.
   a) Labor is still available without too many constraints or shortages.

b) There are no intermediate level machines available for cutting rice stalk. Mechanical harvesting can only be accomplished with binders or combine harvesters. Both are capital intensive and labor efficient (the combine moreso than the binder).

3. Field drying and handling of stalk paddy should be minimized.

   a) Both extend the exposure of the stalk paddy to additional losses by sunchecking, bird and rodent damage as well as shattering. Sun-checking may increase up to 99 percent, depending on variety. Bird and rodent losses as well as shattering losses may increase to 64 kg/ha and 22 kg/ha if left until 40 days after 50 percent heading.

   b) Transporting and stacking of cut stalk is not recommended as the moisture content when harvested at the optimum 20 to 25 percent is too high even after some field drying is performed. Stacking at this high moisture content leads to losses in quality and quantity of the final output. (Stacking losses were not studied directly in this research.)

4. The foot pedal drum thresher is strongly recommended over the other three methods studied, namely the buffalo treading, tractor treading and mechanical threshing.
   a) The pedal thresher can be moved to the field eliminating transport losses and reducing the handling losses only to the bundling operations. Bundling losses may be eliminated if the thresher is moved in the field, behind the collecting operation.
   b) The high moisture rice paddy can be immediately threshed on the field with a pedal drum thresher.
   c) Cracked paddy rice kernels can be reduced by up to 11 percent when harvested on the 28th day after 50 percent heading, when compared to the buffalo and tractor threshing methods.
   d) The foot pedal drum thresher is a simple, low-cost, fairly labor intensive technology appropriate for intermediate levels of mechanization.
5. Simulation modeling should be utilized for planning rice development and expansion programs for predicting loss reductions, technology requirements and labor needs.
   a) A systems analysis of the off field post production subsystem to determine the weakness

in drying, storage and marketing systems is recommended.

b) The in-field model and the off-field model should be used together to determine the weaknesses in the total post production system.

CHAPTER VIII

CONCLUSIONS

Based on the field measurements, analysis and systems modeling of this research, the following conclusions are presented.

1. The average grain moisture content in all the selected varieties investigated began to decrease with the onset of maturity and continued beyond. Longer growth durations of 4 to 4-1/2 month varieties (H-4, BG. 11-11 and BG. 90-2) showed a slower rate of moisture decrease from 16 to 40 days after 50 percent heading than the shorter growth period, 3 to 3-1/2 month varieties (BG. 94-1 and BG. 34-8). The moisture content reduction was 26 to 19 percent and 24.8 to 15.5 percent respectively after the 36th day beyond 50 percent heading.

2. Delays in the cutting operation increased grain losses before cutting for all varieties. Loss rates varied from a high of 9 to 29 kg/ha to a low of 2.5 to 11.5 kg/ha for different varieties, from 16 days to 40 days after 50 percent heading.

3. Harvesting grain losses increased when cutting was delayed beyond maturity. Losses varied from a high of from 9 to 43 kg/ha to a low of 2 to 16 kg/ha, depending on variety, from 16 days to 40 days after 50 percent heading.

4. Handling losses during the bundling operation increased after maturity and beyond. Losses varied from a high of from 4.5 to 32 kg/ha to a low of 1.5 to 12.5 kg/ha, depending on variety, from 16 days to 40 days after 50 percent heading.

5. Grain losses at transport increased with maturity and had the largest grain losses in the handling operations. The losses varied from a high of 73 kg/ha for BG. 11-11 to a low of 32 kg/ha for H-4, both at 40 days after 50 percent heading.

6. Bird and rodent losses increased with maturity and a decrease in grain moisture. The losses varied from a high of 2.5 to 65.5 kg/ha to a low of 7 to 17 kg/ha from 16 to 40 days after 50 percent heading, depending on variety. Grain losses were not influenced by varietal characteristics alone. Losses were also influenced by bird and rodent population, as well as the presence of humans within the proximity of the fields.

7. The proportion of sunchecked kernels increased with delayed harvesting. The proportion of sunchecks varied from a high of 23 to 98 percent to a low of 6 to 61 percent on the 16th and 40th day and 24th and 60th day after 50 percent heading, respectively. Sunchecking was variety dependent.

8. The proportion of broken grain caused by all of the tested threshing methods for the selected varieties were lowest at around the 28th day after 50 percent heading.

9. In all varieties the pedal thresher had the lowest percentage of broken grains. BG. 34-8 had 6 percent brokens at 16 days when a pedal machine was used for threshing. The percentage of broken grains reduced to 3 percent on the 28th day and increased to 7 percent on the 40th day. Broken grains for tractor and buffalo threshing were 26 and 24 percent respectively at 16 days and reduced to 18 and 10.5 percent respectively at 28 days after 50 percent heading. Losses due to mechanical threshing reduced from 22.5 to 9 percent from 16 days to 28 days after 50 percent heading, and increased to 23 percent at 40 days.

10. The simulation model for the in-field post rice production operation illustrated the influence of environment and labor on grain losses for selected varieties. Rain affected the total time required to perform all harvesting operations. In the simulation example, variety BG. 11-11 harvested on the 40th day after 50 percent heading had 7 rainy days and required 14 days to complete all harvesting and threshing operations on the sample 0.94 ha of land. The cutting operation simulated on the 16th day after 50 percent heading had no rainy days during the harvesting and threshing operations of the 0.94 ha. The total operation was completed in 6 days. Stalk paddy cut on the 16th day had 4 rainy days and required 11 days to complete harvesting and threshing operations.

Rain affected the field threshing operations after the stalk paddy was cut. If rain occurred, the cut stalk paddy was, in all cases, transported off the field for threshing. The transport operation, therefore, caused more grain losses regardless of the type of threshing operation.

11. Simulated rain delay for completion of harvesting operations resulted in increased grain losses. Similar results were obtained in simulating the systems using the tractor, buffalo and machine for threshing.

12. An increase in labor use was simulated when the stalk paddy was harvested on the 32nd and 40th day after 50 percent heading. The additional labor requirement of 15 and 11 units respectively was utilized to transport the stalk paddy on rainy days where field threshing could not be performed.

13. The percentage of sunchecked grains in the simulation increased beyond maturity. The simulated average grain moisture content decreased with maturity. The percentage cracked grains using different threshing methods were lowest around the 28th day after 50 percent heading. The pedal threshing method had the least losses as compared to the tractor, buffalo and mechanical methods.

14. The total grain loss for the simulated system using the tractor, buffalo and machine increased from about 40 kg to 225 kg for the 16th and 40th day after 50 percent heading. Total grain losses for the pedal thresher were

lower except on the 32nd and 40th day when rain affected the cutting operation and the cut stalk had to be transported. The total grain loss on the 32nd and 40th day was 169.8 kg and 231.4 kg respectively.

15. The systems analysis helped identify and emphasize the areas of weakness in the technology investigated. Shattering losses associated with delayed harvesting increased handling losses in the cutting, bundling and transport operations. Transport losses were observed to be the highest. Threshing methods as associated with harvesting times were observed to affect the percentage of broken grains.

16. The simulated pedal threshing operation had the least grain losses when compared with the tractor, buffalo and mechanical systems. Handling losses were reduced due to field threshing. The pedal thresher had the lowest percentage of broken grains when the rice was harvested at the optimum time. The pedal thresher was the best alternative technology when used in small farmers' fields.

17. The simulation model is adaptable to a wide range of varietal, weather and labor conditions. The model can be aggregated on a district, regional or county basis. Subsystem models of the off-field post production process could be incorporated to the in-field model so as to cover all phases from production to marketing.

BIBLIOGRAPHY

BIBLIOGRAPHY

Amerasinghe, Nihal, 1972. "The Impact of High Yielding Varieties of Rice on a Settlement Scheme in Ceylon". Modern Ceylon Studies. Vol. III, No. 1, University of Sri Lanka.

Anonymous, 1977. "Storage of Paddy". Paper presented at the Training Course in Processing for Final Year B.Sc. (Agric) Students of the University of Sri Lanka. Rice Processing Development Center, Anuradhapura, Sri Lanka, 9th-13th May.

Anonymous, 1974. "Pest Control in Rice". Pans Manual. No. 3, Center for Overseas Pest Research, Foreign and Commonwealth Office, Overseas Development Administration, London.

Araullo, E. V., D. B. de Padua and Michael Graham, 1976. Rice: Postharvest Technology. International Development Research Center, Ottawa, Canada.

Arora, V. K., S. M. Henderson and T. H. Burkhardt, 1973. "Rice Drying Cracking Versus Thermal and Mechanical Properties". ASAE Transactions. Vol. 16, No. 2.

Ashan, Ekramul and K. A. Haque, 1975. "Appropriate Technology for the Cultivation of HYV (Rice) and their Socio-Economic Implications". Paper No. 29, International Seminar on Socio-Economic Implications of Introducing HYV's in Bangladesh. April 9-11.

Beachell, Henry M. and Peter R. Jennings, 1964. "Needs for Modification of Plant Type in the Mineral Nutrition of the Rice Plant". Proceedings of a Symposium at the IRRI. The Johns Hopkins Press, Baltimore.

Bhalerano, S. G., 1930. "The Grain Shedding Character and its Importance". Bulletin of Agricultural Research Institute. No. 205, Pusa.

Bhattacharyya, K. K. and B. N. Chatterjee, 1977. "Studies on the Maturity of Rice Grains". The RPEC Reporter. Rice Processing Engineering Center, Indian Institute of Technology, Kharagpur, Vol. 3(1).

Bhole, N. G., S. Lal, V. V. Rama Rao and J. Wimberly, 1970. RPEC, India. Publication 701, Indian Institute of Technology, Kharagpur, India.

Burmistrova, M. F., et al., 1963. "Physiochemical Properties of Agricultural Crops". Jerusalem, Translation IPST.

Chorafas, Dimitris N., 1964. "Systems and Simulation". Mathematics in Science and Engineering. Vol. 14, Academic Press, Baltimore.

Chung, Chang Joo, Whoa Seng Kang and Chong Ho Lee, 1977. "Determining of Optimum Timing of Paddy Harvesting Based on Grain Loss and Milling Quality". Department of Agricultural Engineering, College of Agriculture, Seoul National University, Suwon, Korea.

Collier, William L., Gunawan Wiradi and Soentora, 1973. "Recent Changes in Rice Harvesting Methods". Agricultural Development Council, New York.

Contado, Tito E. and Roger A. Jaime, 1975. "Baybay, Leyte". Changes in Rice Farming in Selected Areas of Asia. IRRI, Los Banos, Philippines.

Cooke, Ratna S., 1976. "Water Management in Sri Lanka". Paper presented at a workshop on Implementing Public Irrigation Programs, East-West Food Institute, Honolulu, Hawaii, August 18-31.

Coyard, Y., 1950. "Le Riz. Etude botanique, génétique, physiologique, agrologique et technologique appliquée à l'Indochina". Archives de l'office, Indochinois du Riz (Saigon) No. 50, 312.

Curfs, H. P. F., 1974. "Rice Harvesting and Threshing". Paper presented at the Expert Consultation Meeting on the Mechanization of Rice Production. International Institute of Tropical Agriculture, Ibadan, Nigeria.

De Datta, Surajit K. and Vernon E. Ross, 1975. "Cultural Practices for Upland Rice". Major Research in Upland Rice. IRRI, Los Banos, Philippines.

Director, Stephen W. and Ronald A. Rohrer, 1972. Introduction to Systems Theory. McGraw-Hill, Kogakusha, Ltd.

Dobelmann, J. P., 1961. "Effect of Drying Methods (before threshing) on Milling Yield and Quality of Milled Rice". Manuel de Riziculture Amelioree. Tananarive.

Domrös, Manfred, 1974. "The Agroclimate of Ceylon". Geoecological Research. Vol. 2, Franz Steiner Verlag GMBH, Wiesbaden, 1974.

Duncan, Acheson J., 1955. Quality Control and Industrial Statistics. Richard D. Irwin, Inc., Homewood, Illinois.

Dungan, G. H. and W. A. Ross, 1957. Growing Field Crops. McGraw-Hill Book Company, New York, U.S.A.

Efferson, J. Norman, 1974. "Rice in Tomorrow's World". Paper presented at the Workshop on Rice Post Harvest Technology in the Next Decade. RPEC, Indian Institute of Technology, Kharagpur, India.

Esmay, M. L., Soemangat, Eriyatno and A. Phillips, 1977. Draft of Manual on Rice Post Production Technology, East-West Center, Honolulu, Hawaii (in print).

Fisher, R. A. and F. Yates, 1974. Statistical Tables for Biological, Agricultural and Medical Research. Longmans Group Ltd.

Funomilayo, O. and M. Akande, 1977. "Vertebrate Pests of Rice in South Western Nigeria". Pans, Vol. 23, No. 1, Center for Overseas Pest Research, London.

Gabrial, K. R. and J. Newmann, 1962. "A Markov Chain Model for Daily Rainfall Occurrence at Tel Aviv". Quarterly Journal of the Royal Meteorological Society 88(375). January.

Grist, D. H., 1975. Rice. Fifth Edition, Longmans, London.

Gupta, C. P., 1963. "Rice Engineering Research". Department of Agricultural Engineering, IIT, Kharagpur, India.

Hanumantha Rao, K., 1935. "A Simple Device for Estimating Shedding in Rice". Madras Agricultural Journal, 23:77-78.

Herrera, Romeo T., 1975. "Gapan, Nueva Ecija". Changes in Rice Farming in Selected Areas of Asia. IRRI, Los Banos, Philippines.

Hoshikawa, K., 1972. "Studies on the Development of the Endosperm in Rice. 1. Process of Endosperm Tissue Formation". Nippon Sakumotsu, Gakka, Kiju 36:15. as reported by Juliano, B. O. in Rice: Chemistry and Technology. Ed. American Association of Cereal Chemistry Inc., Minnesota.

Huysmans, A. A. C., 1965. "Milling Quality of Paddy as Influenced by Timing of the Harvest". International Rice Commission Newsletter, Vol. XIV, No. 3.

Ilangantileke, Sarath G., 1978. "In-Field Post Production Losses on Small Farms in Sri Lanka". A paper presented at the workshop on Grain Post Harvest Technology, Department of Agriculture, Royal Thai Government and S.E. Asian Cooperative Post-Harvest Research and Development Program, Bangkok, Thailand, January 10-12.

Ito, Kenji, Jun Inouye and Kenji Takai, 1968. "Studies on Grain Shedding in Some Crops. On the Measuring Methods of Grain Shedding in Rice Plants". (In Japanese, English Summary) Proceedings of Crop Science Society of Japan (38).

Jacobi, B., 1974. "Some Aspects of Rice Harvesting and Threshing Operations in Orissa". Paper presented at the Expert Consultation Meeting on the Mechanization of Rice Production, International Institute of Tropical Agriculture, Ibadan, Nigeria, June 10-14.

Jones, James W., Rex F. Colwick and E. Dale Threadgill, 1972. "A Simulated Environmental Model of Temperature, Evaporation, Rainfall and Soil Moisture". ASAE Transaction.

Jones, James W., 1970. "A Simulated Environmental Model of Temperature, Evaporation, Rainfall and Soil Moisture". Unpublished M.S. Thesis, Mississippi State University.

Khan, Amir U., 1976. "Harvesting and Threshing Equipment and Operations". Rice Post Harvest Technology. Eds. IDRC, Ottawa, Canada.

Khan, Amir U., Fred E. Nichols and Bart Duff, 1973. Semi Annual Program Report No. 16. January 1 to June 30, IRRI, Los Banós, Laguna, Philippines.

Koga, Y., 1977. "Rice Post Harvest Process in Japan". Agricultural Mechanization in Asia, Vol. VIII, No. 3, Summer.

Kono, M. and J. Takahashi, 1961. "Study on the Relationship between Breaking Strength and Chemical Components of Paddy Stem". Journal of Science, Soil and Manure. Japan. 32(4).

__________, 1961. "Study on the Effect of Potassium on the Breaking Strength of Paddy Stem". Journal of Science, Soil and Manure. Japan. 32(11).

Kramer, Harold A., 1951. "Engineering Aspects of Rice Drying". Agricultural Engineering. 32(1).

Langfield, E. C. B., 1957. "Time of Harvest in Relation to Grain Breakage on Milling of Rice". Journal of Australian Institute of Agricultural Science, 23(4).

Manetsch, Thomas J. and Gerald L. Park, 1974. Systems Analysis and Simulation with Applications to Economic and Social Systems. Parts I and II. Department of Electrical Engineering and System Science, Michigan State University, East Lansing, Michigan, Preliminary Edition.

Maranan, Celarina L. and Bart Duff, 1978. "Farm Level Post Production System in the Bicol Region of the Philippines (A Progress Report)". Presented at the Workshop on Grain Post Harvest Technology, Bangkok, Thailand, January 10-12.

Matsuo, T., 1952. "Theory and Practice in Rice Cultivation". National Institute of Agricultural Science Bulletin, Ser. D.3.

Matsushima, Seizo, 1970. "Crop Science in Rice". Theory of Yield Determination and Its Applications. Fuji Publishing Co. Ltd., 1-26, Nishigahara, Kita-ku, Tokyo, Japan.

Nagamatsu, T. and F. Ishikawa, 1954. "Studies on the Geographical Distribution of Characters in Cultivated Areas. VII. Variations of Grain Character and its Geographical Distribution". Science Bulletin, Faculty of Agriculture, Kyushu University, 14.

Nichols, F. E., 1974. "Factors in Establishing Test Procedures Under Local Conditions for Harvesting and Threshing Machinery". in the Report of the Expert Consultation Meeting on the Mechanization of Rice Production, International Institute of Tropical Agriculture, Ibadan, Nigeria, June 10-14.

Nie, Norman H., C. Hadlai Hull, Jean G. Jenkins, Karin Steinbrenner and Dale H. Bent, 1975. SPSS, Statistical Package for Social Scientists. Second Edition, McGraw-Hill.

Ohja, T. P., 1974. "Drying of Paddy". Training Manual: Post Harvest Prevention of Waste and Losses of Food Grains. Asian Productivity Organization, Japan.

Pan, C. L., 1971. "Report to the Government of Sudan on Rice Production". FAO of U.N., Rome, Italy. Reported by Bhole, N. G. "Recent Advances in Pre-Processing, Handling and Threshing of Rice". Paper presented at the Inter-Regional Seminar on the Industrial Processing of Rice, Madras.

Paul, W. R. C., 1945. Paddy Cultivation. Ceylon Government Press.

Peng, Tien-Song, 1977. "The Development of Mechanized Rice Culture and Its Problems in Taiwan". Plant Industry Division, Joint Commission on Rural Reconstruction Industry of Free China, November.

Pereira, B. D. E. M., and F. S. Y. Samuel, 1976. "Processing Methods--Sri Lanka". Rice Post Harvest Technology. Eds. IDRC, Ottawa, Canada.

Pillai, Subbiah M., 1958. "Cultural Trials and Practices of Rice in India". Central Rice Research Institute, Cuttack, India.

Pillaiyar, P., S. Sethuraman and T. Ramanujan, 1977. "Causes and Prevention of Pre-Harvest Rice Losses. Benefits of Pre-Harvest Sprays for Early Ripening and Harvest". Paper Presented at the Action Oriented Field Workshop for Prevention of Post Harvest Rice Losses, Kedha, Malaysia, March 12-30.

Prakash, Ishwar, 1974. "Rodent Damage in the Field and Their Control". Training Manual: Post Harvest Prevention of Waste and Loss of Food Grains. Asian Productivity Organization, Japan.

Ramaih, K. and M. B. V. N. Rao, 1953. Rice Breeding and Genetics. Indian Council of Agriculture Research, Science Monograph, No. 19.

Rice Production Manual, Revised Edition by the University of the Philippines, College of Agriculture and International Rice Research Institute, Los Banós, Philippines.

Ruiz, E., 1965. "Harvest Losses of Palay Grains of BP-121 Lowland Rice Variety at Different Levels of Moisture Content". Central Luzon State University Science Journal 1(2).

Sass, Joseph C., 1974. Fortran IV, Programming and Applications. Holden-Day Inc., San Francisco.

Singh, K. N. and T. H. Burkhardt, 1974. "Rice Plant Properties in Relation to Lodging". ASAE Transactions Volume No. 6.

Smith and Macrea, Jr., 1951. "Where Breakage Occurs in the Milling of Rice". Rice Journal, 54(2).

Sugimoto, Katsuo, 1965. "Result of Study on Rice Culture". in the Symposium Series, No. 1, Rice Culture in Malaya. The Center for Southeast Asian Studies, Kyoto University.

Tanaka, A., 1964. "Plant Characters Related to Nitrogen Response in Rice". The Mineral Nutrition of the Rice Plant. Proceedings of a Symposium at the International Rice Research Institute, The John Hopkins Press, Baltimore.

__________, 1964. "Examples of Plant Performance". The Mineral Nutrition of the Rice Plant. Proceedings of a Symposium at the International Rice Research Institute, The John Hopkins Press, Baltimore.

Ten Have, I. H., 1961. "The Testing of Promising Varieties of Rice for their Yield of Total Milled Rice and Breakage Resistance". Paper No. IRC/WP/61-67, presented at the IRC Working Party on Rice Production and Protection, New Delhi.

Te-Tzu Chang and Eliseo A. Bardens, 1965. "The Morphology and Varietal Characteristics of the Rice Plant". Technical Bulletin No. 4, IRRI, Los Banós, Laguna, the Philippines.

Toquero, Z., C. Maranan, L. Ebron and B. Duff, 1977. Assessing Quantitative and Qualitative Losses in Rice Post Production Systems". Paper presented at the Action Oriented Workshop for Prevention of Post Harvest Rice Losses, Kedha, Malaysia, March 12-30.

Tsunoda, Shigesaburo, 1964. "Leaf Characters and Nitrogen Response". The Mineral Nutrition of the Rice Plant. Proceedings of a Symposium at the IRRI, The John Hopkins Press, Baltimore.

Umalo, Silvano and Santos, 1956. "A Preliminary Study of Some Factors Affecting the Milling Recovery of Rice in the Philippines". The Philippine Agriculturalist. (Laguna), 40(2).

Verma, S. K. C., 1969. "Mechanical Control of Lodging in Rice". Madras Agricultural Journal. 56(1).

Vo-Tong, Xuan and Vernon E. Ross, 1976. Training Manual for Rice Production. IRRI, Los Banos, Laguna, The Philippines.

Wanders, A. A., 1974. "International and Coordinated Research Project on Rice Mechanization- GP4/1 TE INT 43(NET) Rice Harvesting and Threshing". Paper presented at the Expert Consultation Meeting on the Mechanization of Rice Production, International Institute of Tropical Agriculture, Ibadan, Nigeria, June 10-14.

Weeraratne, W., B. D. E. M. Pereira and M. Yogendran, 1977. "Sri Lanka Report on Post Harvest Rice Losses". Country report presented at the Workshop for Prevention of Post Harvest Losses, Kedha, Malaysia, March 12-30.

Wikramanayake, V. E. A. and J. E. Wimberly, 1975. "Rice Report". Instituto De Agroqurica Y Technologia De Alimentos, Spain.

Wimberly, J. E., 1975. "Ford Foundation International Rice Research Institute, Post Production Projects in India and Sri Lanka". Presented at a Planning Meeting on Post Harvest Crop Protection, East-West Food Institute, Honolulu, Hawaii.

APPENDICES

APPENDIX A1

'SHAZAM"

Statistical Program

and

Results for BG. 94-1

```
SHAZAM (VERSION 2.4 - AUG 1978)     SOL 8 14
GE X9=X1**2

DATA FORMAT CARD = DA
......EFFICIENT REGION SET TO  9 VARIABLES AND       1344 OBSERVATIONS

FIRST FIVE INCLUDED AND LAST OBSERVATION
```

1	16.000	26.000	3.9000	3.9200	9.4300	25.000	1.5300	4.0000	256.00
2	16.000	26.000	4.9000	2.5200	4.5000	27.000	.72000	6.0000	256.00
3	20.000	23.480	4.1000	7.4300	4.3000	42.600	5.4000	8.0000	400.00
4	20.000	23.800	3.3600	8.9400	9.2000	36.840	4.7100	8.0000	400.00
5	24.000	20.820	10.100	12.650	6.4300	44.700	22.500	16.000	576.00
14	40.000	20.650	14.300	58.750	20.360	67.300	100.90	34.000	1600.0

.NOTE..OUTPUT IS EASIER TO READ IF YOU USE VN CARDS

SHAZAM (VERSION 2.4 - AUG 1978) SOL 8 14

NUMBER OF OBSERVATIONS= 14
NUMBER OF INPUT VARIABLES= 8
USING OBSERVATIONS 1 THRU 14
NUMBER OF VARIABLES AFTER TRANSFORMATION = 9

VARIABLE NAME	NO.	MEAN	STANDARD DEVIATION	VARIANCE	MINIMUM	MAXIMUM
	1	28.000	8.3020	68.923	16.000	40.000
	2	21.131	2.6441	6.9911	17.640	26.000
	3	9.2414	4.2620	18.165	3.3600	15.220
	4	19.339	15.364	236.04	2.5200	58.750
	5	9.7029	4.0601	16.484	4.3000	20.360
	6	41.776	11.654	135.81	25.000	67.300
	7	27.988	29.888	893.27	.72000	100.90
	8	19.000	11.787	138.92	4.0000	38.000
	9	848.00	468.46	.21945D+06	256.00	1600.0

SUBPROBLEM NO. 1 SOL 8 14
OLS 2 1 9 MAX
THIS PROBLEM CAN BE RUN WITH PAR= 2

DEPENDENT VARIABLE = 2 14 OBSERVATIONS

R-SQUARE = 0.9561 R-SQUARE ADJUSTED = 0.9481 BARTENS R-SQUARE = 0.9471
VARIANCE OF THE ESTIMATE = .36262
STANDARD ERROR OF THE ESTIMATE = .60218
NORMALIZED DETERMINANT OF MATRIX = .15075D-01
HAITOVSKY MULTICOLLINEARITY TEST $ CHI-SQUARE = 0.1696 WITH 3 DEGREES OF FREEDOM
LOG OF THE LIKELIHOOD FUNCTION(IF DEPVAR LINEAR) = -11.0761
LOG OF THE LIKELIHOOD FUNCTION(IF DEPVAR LOG) = -306.916

ANALYSIS OF VARIANCE

	SS	DF	MS	F
EXPLAINED	86.895	2.	43.448	119.817
UNEXPLAINED	3.9888	11.	.36262	
TOTAL	90.884	13.	6.9911	

VARIABLE NAME	NO.	ESTIMATED COEFFICIENT	STANDARD ERROR	T-RATIO 11 DF	PARTIAL CORR.	STANDARDIZED COEFFICIENT	ELASTICITY AT MEANS
	1	-1.7116	.16385	-10.446	-0.95312	-5.3742	-2.2679
	9	.26031D-01	.29037D-02	8.9647	0.93787	4.6119	1.0446
INTERCEPT		46.982	2.1712	21.639			

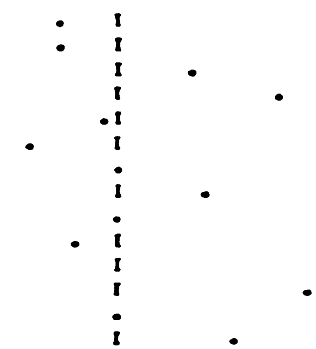
VARIANCE-COVARIANCE MATRIX OF COEFFICIENTS

VAR			
1	0.2685D-01		
9	-0.4722D-03	0.8431D-05	
INT	-0.3513D+00	0.6071D-02	0.4714D+01
	1	9	

CORRELATION MATRIX OF COEFFICIENTS

VAR			
1	1.00000		
9	-0.99243	1.00000	
INT	-0.98748	0.96291	1.00000
	1	9	

OBSERVATION NO.	OBSERVED VALUE	PREDICTED VALUE	CALCULATED RESIDUAL
1	26.000	26.260	-.26049
2	26.000	26.260	-.26048
3	23.480	23.163	.31750
4	23.800	23.163	.63749
5	20.820	20.897	-.775080D-01
6	20.520	20.897	-.37751
7	19.480	19.465	.145200D-01
8	19.840	19.465	.37452
9	18.880	18.866	.135610D-01
10	18.680	18.866	-.18644
11	17.640	19.100	-1.4604
12	19.910	19.100	.80963
13	20.140	20.167	-.272630D-01
14	20.650	20.167	.48273



DURBIN-WATSON STATISTIC = 2.3134   VON NEUMAN RATIO = 2.4913   FIRST-ORDER RHO = -0.2065
RESIDUAL SUM = -.79956D-04   RESIDUAL VARIANCE = .36261
SUM OF ABSOLUTE ERRORS= 5.3000
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9561
COEFFICIENT OF SKEWNESS =-1.1742 WITH STANDARD DEVIATION OF 0.5974
COEFFICIENT OF KURTOSIS = 2.9939 WITH STANDARD DEVIATION OF 1.1541

GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 6 GROUPS
OBSERVED 1.0 0.0 6.0 5.0 2.0 0.0
EXPECTED 0.3 1.9 4.8 4.8 1.9 0.3
CHI-SQUARE = 4.0015 WITH 1 DEGREES OF FREEDOM

END OF SUBPROBLEM 1
0.151 SEC. CPU TIME

```
FORTRAN IV G1  RELEASE 2.0          LABOR          DATE = 78277          00/11/51          PAGE 0001

      SUBROUTINE LABOR(LM)
      DIMENSION R(200)
      REAL NMLVAL(41)
      NMLVAL(1)=-3.500
      NMLVAL(2)=-1.960
      NMLVAL(3)=-1.645
      NMLVAL(4)=-1.439
      NMLVAL(5)=-1.281
      NMLVAL(6)=-1.150
      NMLVAL(7)=-1.037
      NMLVAL(8)=-.925
      NMLVAL(9)=-.841
      NMLVAL(10)=-.755
      NMLVAL(11)=-.674
      NMLVAL(12)=-.598
      NMLVAL(13)=-.524
      NMLVAL(14)=-.454
      NMLVAL(15)=-.386
      NMLVAL(16)=-.312
      NMLVAL(17)=-.253
      NMLVAL(18)=-.189
      NMLVAL(19)=-.126
      NMLVAL(20)=-.056
      NMLVAL(21)=0
      NMLVAL(22)=.056
      NMLVAL(23)=.126
      NMLVAL(24)=.189
      NMLVAL(25)=.253
      NMLVAL(26)=.312
      NMLVAL(27)=.386
      NMLVAL(28)=.454
      NMLVAL(29)=.524
      NMLVAL(30)=.598
      NMLVAL(31)=.674
      NMLVAL(32)=.755
      NMLVAL(33)=.841
      NMLVAL(34)=.925
      NMLVAL(35)=1.037
      NMLVAL(36)=1.150
      NMLVAL(37)=1.281
      NMLVAL(38)=1.439
      NMLVAL(39)=1.645
      NMLVAL(40)=1.960
      NMLVAL(41)=3.500
      CALL   GGUB (1368528204,200,R)
      Y=FNL(NMLVAL,0.,.025,40,R(23))
      SSDL=2.1
      SMNL=5
      XX=SSDL*Y+SMNL
      LM=XX
      RETURN
      END
```

APPENDIX A2

'LABOR' Subroutine and NMLVAL array

```
FORTRAN IV G1  RELEASE 2.0          FNL          DATE = 78277          09/11/51          PAGE 0001

          FUNCTION FNL (DVAL,XS,DX,N,X)
          DIMENSION DVAL(200)
       1  IF(X-XS) 3,3,2
       2  IF(X-XS-N*DX) 7,5,5
       3  FNL=DVAL(1)
       4  GO TO 10
       5  FNL=DVAL(N+1)
       6  GO TO 10
       7  XD=X-XS
       8  I=1.0+XD/DX
       9  FNL=(XD-FLOAT(I-1)*DX)*(DVAL(I+1)-DVAL(I))/DX+DVAL(I)
      10  RETURN
          END
```

APPENDIX A3

'FNL' Subprogram

```
FORTRAN IV G1  RELEASE 2.0            RAIN            DATE = 78277         00/11/51              PAGE 0001

0001              SUBROUTINE RAIN(K,M,WK11,NSIZE)
0002              INTEGER WK11(NSIZE)
0003              DIMENSION R(200)
0004              IF(K.EQ.1)  GO TO 6
0005              PWD=0.70806-1.1123*WK11(M)+0.69947*(WK11(M)**2)-.20151*(WK11(M)**3
                 5)+.28819E-01*(WK11(M)**4)-0.19758E-02*(WK11(M)**5)+0.51777E-04*(WK     W1
                 611(M)**6)                                                              W1
0006              PR=1-PWD
0007              CALL  GGUB (1254930562,200,R)
0008              IF(R(6).LT.PR)  K=0
0009              IF(R(6).GT.PR)  K=1
0010              GO TO 8
0011            6 PWW=2.0356-2.7443*WK11(M)+1.5785*(WK11(M)**2)-0.40824*(WK11(M)**3)    D1
                 7+0.52509E-01*(WK11(M)**4)-0.32797E-02*(WK11(M)**5)+0.79313E-04*(WK     D1
                 811(M)**6)                                                              D1
0012              PR=1-PWW
0013              CALL GGUB (2038483640,200,R)
0014              IF(R(12).LT.PR)    K=0
0015              IF(R(12).GT.PR)    K=1
0016            8 RETURN
0017              END
```

APPENDIX A4

'RAIN' Subroutine

APPENDIX A5

Transport Rate

Av. area of head carried bundle (B)	= 24.87 m^2
	= 0.0025 ha
Distance to the threshing floor (D)	= 216 m^2
Av. Speed of transporter (X)	= 2414 m/hr
Transport rate per trip	= X/D*½*B
	= 0.014 ha/hr

APPENDIX A6

Bundling Rate

Av. area bundled/hr	= 1233.5 ft^2/hr
	= 2467 ft^2/hr
	= 0.5 acres/hr
	= 0.23 ha/hr

APPENDIX A7

Pedal Threshing Rate

Av. threshing time for 5 m^2 plots	= 3.2 minutes
	= 5 m^2/3.2 minutes
	= 1.52 m^2/minute
	= 91.20 m^2/hr
	= .009 ha/hr

APPENDIX A8

Buffalo Threshing Rate

Av. time to thresh 5 m^2/pair of buffalos	= 15 minutes
Threshing rate/pair of buffalos	= 5 m^2/15 minutes
	= 0.33 m^2/minute
	=19.8 m^2/hr
	= 0.002 ha/hr

APPENDIX A9

Tractor Threshing Rate

Av. time to thresh 0.25 acres	= 1 hour
Threshing rate	= 0.25 acres/hr
	= 0.1 ha/hr

Mechanical Threshing Rate

Av. time to thresh 5 m^2 with the machine	= 2 minutes
Threshing rate/machine	= 5 m^2/2 minutes
	= 2.5 m^2 minute
	= 150 m^2hr
	= 0.015 ha/hr

APPENDIX A10

Main Program With the

Pedal Threshing Model

and

Results

Pedal Threshing Model Card 113-269

```
      INTEGER WK11(300)
       JK=90
      DO 50 IM=1,JK
      READ 51,IWK
   51 FORMAT(24X,I4)
      WK11(IM)=IWK
   50 CONTINUE
      M=0
      III=0
      LLL=0
      I=16
   68 N=I-1
C-
C-*************************-INPUT VARIABLES-***************************************
C-
      RLODG=0.25
      LABF=3
      LABPT=4
      LABM=3
      LABRF=6
      LABTP=4
      PH=0.02
      FLAND=0.94
      DT=0.05
      X=2414
      D=217
      B=.0025
      TRAC=.1
      TM=.01
      THF.005
      NUPP=4
C-*********************************************************************************
      LABTCT=0
      BNDT=0.0
      PND=0.0
      ST=0.0
      ATP=0.0
      ATT=0.0
      K=0
      STI=0.0
      APT=0.0
      ST=0.0
      PH=0.0
      PHVT=0.0
      PSVT=0.0
      PPDT-0.0
      BNDLT=0.0
      TRLT=0.0
      AT=0.0
        DH=0.0
      H=PLAND
      PLDG=1.0-FLODG
      NN=B/DT+4
      TPTH=NOPP*TD
      PRINT 100
  100 FORMAT(2X,'TIME       HA TO       HA         HA TO       HA TO
     6HA          HA TO       HA'/                  10X, 'HAVST      HAVS
     8TD          BNDL        TRNSPT      TRSPTD      THRSH       THPSD'/'****
```

```
         3**********************************************************'//)
            GO TO 3
          2 PRINT 4,N
          4 FORMAT(4X,'DATE =',2X,I3,4X,'RAIN, NO HARVEST'//)
            PRINT 150,GAV,SNC,PHV,     PHVT,BRD,TBRD,BRDT
            PHVT=0.0
            BRDT=0.0
          3 N=N+1
            BKI=58.972-2.9741*N+0.5465E-01*(N**2)
            PRINT 172,BKI
        172 FORMAT(25X,'% BROKEN GRAIN =',5X,F7.2/)
      C-*****************************************************************aaaaaaaaaaaa*
            GAV=18.71+0.51263*N-0.13181E-01*(N**2)
            SNC=-27.357+3.1637*N                                          11-11
            BRD=-37.559+2.5402*N
            PHV=-4.3123+0.66924*N
      C-*****************************************************************aaaaaaaaaaaa*
            TPHV=PHV*(PLAND-DH)
            PHVT=PHVT+TPHV
            TBRD=BRD*(PLAND-DH)
            BRDT=BRDT+TBRD
            M=M+1
            CALL RAIN(J,M,WK11,300)
            IF(J.EQ.1)  GO TO 2
            CALL LABOR(LI)
            LABH=LABH+LI
            IF(LABH.LT.5)   PRINT 61
         61 FORMAT(13X,'NO LABOR FOR HARVEST'//)
            IF(LABH.LT.5)   GO TO 3
            LABTOT=LABTOT+LABH
            PRINT 5,N,LABH
          5 FORMAT(4X,'DAY =',2X,I3,2X,'LABOR =',2X,I4,10X,'NO RAIN, LABOR
           5AVAILABLE, HARVEST'//)
            PRINT 150,GAV,SNC,PHV,     PHVT,BRD,TBRD,BRDT
        150 FORMAT(25X,'GRAIN MOISTURE%=',2X,F6.2/25X,'SUN CHECKS%=',2X,F7.2/
           125X,'PRE HARVEST LOSSES(KG/HA)=',2X,F8.2/
           2                          25X,'TOTAL LOSS PRE HARVEST(KG)=',2X,F
           38.2/25X,'BIRD & RODENT LOSSES(KG/HA)=',2X,F8.2/25X,'BIRD & RODENT
           4LOSSES FOR TOTAL AREA(KG)=',2X,F8.2/25X,'TOTAL BIRD & RODENT LOSSE
           5S(KG)=',2X,F8.2/)
            GO TO 6
          8 PRINT 7,N,LABH
          7 FORMAT(4X,'DAY =',2X,I3,2X,'LABOR =',2X,I4,10X,'NO RAIN, LABOR
           7AVAILABLE, HARVEST'//)
            PRINT 150,GAV,SNC,PHV,     PHVT,BRD,TBRD,BRDT
            LABTOT=LABTOT+LABH
            H=PLAND-DH
          6 T=0.0
            RRH=LABH*RH
            DO 10 J=1,NN
            T=T+DT
            H=H-RRH*DT*RLDG
            DH=DH+RRH*DT*RLDG
      C-****************************************************************aaaaaaaaaa*******
            PSV=-1.1089+1.1246*N                                          11-11
      C-*********************************************QAAAAAAAAAAAAAAAA*****Q*QQ8 aaaa*
            TPSV=PSV*RRH*DT*RLDG
            PSVT=PSVT+TPSV
```

```
      A=DH-BNDT
      IF(H.LT.0.0)  H=0.0
      IF(H.EQ.0.0)  DH=RLAND
      IF(H.EQ.0.0)  GO TO 11
      IF((8.00-T).LT..0001)  GO TO 35
   10 CONTINUE
   11 PRINT 12
   12 FORMAT(4X,'HARVEST COMPLETED'//)
      PRINT  9,T,H,DH,A,AT,ATR,APT,ATT
    9 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,PSVT
  151 FORMAT(25X,'POST HARVEST LOSSES(KG/HA)=', 2X,F8.2/
     6                                         25X,'TOTAL LOSS POST HARVEST(K
     7G)=',2X,F8.2/)
      A=DH-BNDT
      APT=ATR
   13 CONTINUE
C-
C-***************************************************************************
      PRINT 170,APT,ATT
  170 FORMAT(25X,'AREA TO THRESH=',5X,F9.4/25X,'AREA THRESHED=',5X,F9.4/
     6/)
      T=0.0
      N=N+1
C-***************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                          11-11
      SNC=-27.357+3.1637*N                                            11-11
      BRD=-37.559+2.5402*N                                            11-11
C-***************************************************************************
      TBRD=BRD*(RLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.0) GO TO 28
      PRINT 14,N
   14 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN, TRANSPORT'//)
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D*1/2*8
      BR=0.022
  201 CONTINUE
      TRR=TR*LABT
      BRR=BR*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 201
      PRINT 62,LABT,LABB
   62 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     8I4,//)
      BPT=BRR
      LABTOT=LABTOT+LAB
      PRINT 152,GAV,SNC,TBRD,BRDT
  152 FORMAT(25X,'GRAIN MOISTURE%=',2X,F6.2/25X,'SUNCHECK%=',2X,F7.2/25X
     8,'BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=',2X,F8.2/25X,'TOTAL BI
```

```
      9RD AND RODENT LOSSES(KG)=',2X,F8.2/)
       DO 15 IJ=1,NN
       T=T+DT
       A=A-URR*DT
       IF(A.GT.0)  GO TO 16
       A=0.0
       BN=0.
       BPR=0.
       LABBT=LABT+LABB
       TRP=TP+LAPPT
    16 CONTINUE
       BN=BRR*DT
       AT=AT+BN-TRR*DT
       ATR=ATR+TRR*DT
       SI=SI+TPR*DT
       IF(AT.LT.0.0)   AT=0.0
       IF(AT.EQ.0.0)  ATR=DH
       BND=BND+BPT*DT
       IF(A.EQ.0.0)  BND=DH
       IF(A.EQ.0.0)   BNDT=BND
C-@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
       BNDL=-13.189+1.1246*N                                                 11-11
       TRL=-23.206+2.4139*N                                                  11-11
C-@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
       TBNDL=BNDL*BN
       BNDLT=BNDLT+TBNDL
       TTRL=TRL*TPR*DT
       TRLT=TRLT+TTRL
       IF(AT.EQ.0.0)  GO TO 18
       IF((B.00-T).LT..0001)  GO TO  13
    15 CONTINUE
    18 PRINT 19
    19 FORMAT(5X,'HARVST BNDLNG AND TRNSPT COMPLTE'//)
       PRINT 17,T,H,DH,A,AT,ATR,APT,ATT
    17 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
      1F7.4//)
       PRINT 153,BNDL,       BNDLT,TRL,      TRLT
   153 FORMAT(25X,'BUNDLING LOSS (KG/HA)=',2X,F8.2/
      1                    25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/25X
      2,'TRANSPORT LOSS (KG/HA)=',2X,F8.2/
      3              25X,'TOTAL TRANSPORT LOSSES(KG)=',2X,F8.2/)
       APT=SI+APT
       GO TO 20
    21 PRINT 22,N
    22 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN NO THRESHING'//)
    20 PRINT 90 ,APT,ATT
    90 FORMAT(25X,'AREA TO THRESH=',5X,F9.4/25X,'AREA THRESHED=',5X,F9.4/
      6/)
       N=N+1
C-@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
       GAV=18.71+0.51263*N-0.13181E-01*(N**2)                                11-11
C-@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
       M=M+1
       CALL RAIN(J,M,WK11,300)
       IF(J.EQ.1)  GO TO 21
       PRINT 23,N
    23 FORMAT(4X,'DAY =',2X,I3,4X,'NO RAIN THRESH'//)
       LABTOT=LABTOT+LABPT
```

```
      TRTP=TPT*LABPT
      T=0.0
      DO 24 II=1,NN
      T=T+DT
      APT=APT-TRTP*DT
      ATT=ATT+TRTP*DT
      IF(APT.LT.0.0)   APT=0.0
      IF(APT.EQ.0.0)  GO TO 26
      IF((P.DD-T).LT..0001)  GO TO  20
   24 CONTINUE
   26 PRINT 27
   27 FORMAT(4X,'THRESHING COMPLETE'//)
      PRINT 25,T,H,DH,A,AT,ATR,APT,ATT
   25 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     2F7.4//)
      GO TO 55
   28 PRINT 29,N
   29 FORMAT(4X,'DAY =',2X,I3,4X,'NO RAIN, TRANSPORT & THRESH'//)
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D*1/2*H
      BP=0.022
  301 CONTINUE
      TRR=TR*LABT
      BRP=BP*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 301
      PRINT 62,LABT,LABB
      LABTOT=LABTOT+LAB
      HRT=HRR
      TRTP=TPT*LABPT
      PRINT 152,GAV,SNC,TBRD,BRDT
      APT=ST+APT
      LABTOT=LABTOT+LABPT
      T=0.0
      DO 30 MMM=1,NN
      T=T+DT
      A=A-HRR*DT
      IF(A.GT.0)  GO TO 31
      A=0.0
      BN=0.
      BRR=0.
      LABBT=LABT+LABB
      TRR=TR*LABBT
   31 CONTINUE
      BN=BRR*DT
      AT=AT+BN-TRR*DT
      IF(AT.LT.0) AT=0.0
      ATR=ATR+TRR*DT
      IF(AT.EQ.0.0)  ATR=0.0
      ST=TRR*DT
      IF(AT.EQ.0.0)  ST=0.0
      APT=ST+APT-TRTP*DT
      ATT=ATT+TRTP*DT
```

```
      IF(APT.LT.0)  APT=0.0
      SI=0.0
      BND=BND+BPT*DT
      IF(A.EQ.0.0)  BND=DH
      IF(A.EQ.0.0)  BNDT=BND
C-&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&& & &&&&&&&&
      BNDL=-13.189+1.1246*N                                                   11-11
C-&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&& & &&&&&&&&
      TBNDL=BNDL*BN
      BNDLT=BNDLT+TBNDL
      IF(AT+APT.EQ.0) GO TO 33
      IF((6.00-T).LT..0001)  GO TO  13
   30 CONTINUE
   33 PRINT 34
   34 FORMAT(5X,'HAVST,BUND,TRANS,THRESH COPMPLETE'//)
      PRINT 32,T,H,DH,A,AT,ATR,APT,ATT
   32 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     3F7.4//)
      PRINT 155,BNDL,      BNDLT
  155 FORMAT(25X,'BUNDLING LOSS (KG/HA)=',2X,F8.2/
     3                          25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/)
      GO TO 55
C-*************************************************************************
   35 PRINT 36
   36 FORMAT(4X,'HARVEST INCOMPLETE'//)
      PRINT 79,T,H,DH,A,AT,ATR,APT,ATT
   79 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,     PSVT
      A=DH-BNDT
   37 CONTINUE
      T=0.0
   63 N=N+1
C- ************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                                  11-11
      SNC=-27.357+3.1627*N                                                    11-11
      BRD=-37.559+2.5402*N
      PHV=-4.3123+0.66024*N
C-*************************************************************************
      TPHV=PHV*(RLAND-DH)
      PHVT=PHVT+TPHV
      TBRD=BRD*(RLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      CALL LABOR(LI)
      LABH=LABF+LI
      IF(LABH.LT.5)  PRINT 60
   60 FORMAT(10X,'NO LABOR FOR HARVEST'//)
      IF(LABH.LT.5)  GO TO 63
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.0)  GO TO 8
      PRINT 38,N
   38 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN TRANSPORT DH'//)
      PRINT 150,GAV,SNC,PHV,     PHVT,BRD,TBRD,BRDT
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
```

```
      TPT=0.007
      TR=X/D*1/2*B
      DR=0.022
  102 CONTINUE
      TRR=TR*LABT
      BRR=DR*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 102
      PRINT 66,LABT,LABB
   66 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     9I4,//)
      LABTOT=LABTOT+LAB
      BRT=BRR
      DO 39 JJK=1,NN
      T=T+DT
      A=A-BRR*DT
      IF(A.GT.0)  GO TO 40
      BN=0.
      A=0.0
      BRR=0.
      LABBT=LABT+LABB
      TRR=TR*LABBT
   40 CONTINUE
      BN=BRR*DT
      AT=AT+BN-TRR*DT
      ATR=ATR+TRR*DT
      IF(AT.LT.0.0)  AT=0.0
      BND=BND+BRT*DT
      IF(A.EQ.0.0)  BND=DH
      IF(A.EQ.0.0)   BNDT=BND
C-*********************************************************************
      BNDL=-13.189+1.1246*N                                       11-11
      TRL=-23.206+2.4139*N
C-*********************************************************************
      TBNDL=BNDL*BN
      BNDLT=BNDLT+TBNDL
      TTRL=TRL*TRR*DT
      TRLT=TRLT+TTRL
      IF(AT.EQ.0.0)  GO TO 42
      IF((B.00-T).LT..0001)  GO TO  37
   39 CONTINUE
   42 PRINT 43
   43 FORMAT(5X,'BUND AND TRANS OF DH COMPLETE'//)
      PRINT 41,T,H,CH,A,AT,ATR,APT,ATT
   41 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     4F7.4//)
      PRINT 153,BNDL,     BNDLT,TRL,     TRLT
      H=PLAND-DH
      GO TO 3
   55 TOTL=PHVT+PSVT+BRDT+BNDLT+TRLT
      PRINT 160,PHVT,PSVT,BRDT,BNDLT,TRLT,TOTL
  160 FORMAT(25X,'TOTAL PRE HARVEST LOSSES(KG)=',2X,F8.2/25X,'TOTAL POST
     4HARVEST LOSSES(KG)=',2X,F8.2/25X,'TOTAL BIRD AND RODENT LOSSES(KG)
     5=',2X,F8.2/25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/25X,'TOTAL TRA
     6NSPORTATION LOSSES(KG)=',2X,F8.2/25X,'TOTAL GRAIN LOSSES(KG)=',2X,
     7F8.2/)
      PRINT 171,LABTOT
```

```
FORTRAN IV G1  RELEASE 2.0              MAIN               DATE = 78277         00/18/39               PAGE 0008

0352              171  FORMAT(25X,'TOTAL LABOR USED=',5X,I8  //'************************
                      1**********************************************************
                      2*********************'///)
0353                   IF((40-I).LT.0.OR.(40-I).EQ.0)  GO TO 67
0354                   III=I
0355                   I=I+4
0356                   M=(I-III)+LLL
0357                   LLL=LLL+4
0358                   GO TO 68
0359               67  STOP
0360                   END
```

```
*OPTIONS IN EFFECT*  NOTERM,NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
*OPTIONS IN EFFECT*  NAME = FNL       , LINECNT =        60
*STATISTICS*    SOURCE STATEMENTS =         13,PROGRAM SIZE =       686
*STATISTICS*  NO DIAGNOSTICS GENERATED

*STATISTICS*  NO DIAGNOSTICS THIS STEP



                                                      VS LOADER

OPTIONS USED - PRINT,NOMAP,NOLET,CALL,RES,NOTERM,SIZE=233472,NAME=**GO

 TOTAL LENGTH     9848
 ENTRY ADDRESS   87010


 TIME       HA TO        HA          HA TO       HA TO        HA          HA TO        HA
           HAVST      HAVSTD       BNDL       TRNSPT      TPSPTD       THRSH       THRSD
*** ***********************************************************************


                        % BROKEN GRAIN =        25.38

  DAY =    16  LABOR =      6            NO RAIN, LABOR    AVAILABLE, HARVEST


                        GRAIN MOISTURE%=    23.54
                        SUN CHECKS%=     23.21
                        PRE HARVEST LOSSES(KG/HA)=       6.40
                        TOTAL LOSS PRE HARVEST(KG)=       6.31
                        BIRD & RODENT LOSSES(KG/HA)=       3.00
                        BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       2.90
                        TOTAL BIRD & RODENT LOSSES(KG)=       2.90

  HARVEST INCOMPLETE


 8.05      0.2155      0.7245      0.7245      0.0         0.0         0.0         0.0


                        POST HARVEST LOSSES(KG/HA)=       4.80
                        TOTAL LOSS POST HARVEST(KG)=       3.48

  DAY =    17  LABOR =      7            NO RAIN, LABOR    AVAILABLE, HARVEST


                        GRAIN MOISTURE%=    23.62
                        SUN CHECKS%=     26.37
                        PRE HARVEST LOSSES(KG/HA)=       7.06
                        TOTAL LOSS PRE HARVEST(KG)=       7.53
                        BIRD & RODENT LOSSES(KG/HA)=       5.62
                        BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       1.21
                        TOTAL BIRD & RODENT LOSSES(KG)=       4.11

  HARVEST COMPLETED
```

```
                    TOTAL LOSS POST HARVEST(KG)=       4.79

                    AREA TO THRESH=         0.0
                    AREA THRESHED=         0.0

DAY =   18    RAIN, TRANSPORT

      LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     4

                    GRAIN MOISTURE%=   23.67
                    SUNCHECK%=     29.54
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=       4.11

                    AREA TO THRESH=         0.0
                    AREA THRESHED=         0.0

DAY =   19    RAIN, TRANSPORT

      LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     3

                    GRAIN MOISTURE%=   23.69
                    SUNCHECK%=     32.70
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=       4.11
 HARVST BNDLNG AND TRNSPT COMPLTE

6.55     0.0       0.9400     0.0       0.0       0.9400     0.0       0.0

                    BUNDLING LOSS (KG/HA)=       8.18
                    TOTAL BUNDLING LOSSES(KG)=       6.89
                    TRANSPORT LOSS (KG/HA)=      22.66
                    TOTAL TRANSPORT LOSSES(KG)=      20.30

                    AREA TO THRESH=         0.9437
                    AREA THRESHED=         0.0

DAY =   20    RAIN NO THRESHING

                    AREA TO THRESH=         0.9437
                    AREA THRESHED=         0.0

DAY =   21    NO RAIN THRESH

                    AREA TO THRESH=         0.7183
                    AREA THRESHED=         0.2254
```

```
DAY =   23    RAIN NO THRESHING

                     AREA TO THRESH=        0.4928
                     AREA THRESHED=        0.4508

DAY =   24    NO RAIN THRESH

                     AREA TO THRESH=        0.2674
                     AREA THRESHED=        0.6762

DAY =   25    NO RAIN THRESH

                     AREA TO THRESH=        0.0420
                     AREA THRESHED=        0.9016

DAY =   26    NO RAIN THRESH

THRESHING COMPLETE

1.55     0.0       0.9400     0.0       0.0       0.9400     0.0       0.9450

                     TOTAL PRE HARVEST LOSSES(KG)=       7.53
                     TOTAL POSTHARVEST LOSSES(KG)=       4.79
                     TOTAL BIRD AND RODENT LOSSES(KG)=       4.11
                     TOTAL BUNDLING LOSSES(KG)=       6.89
                     TOTAL TRANSPORTATION LOSSES(KG)=       20.30
                     TOTAL GRAIN LOSSES(KG)=       43.62

                     TOTAL LABOR USED=            48
••••••••••••••••••••••• •••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••• ••••••••••••••••••••••


TIME      HA TO      HA        HA TO      HA TO      HA        HA TO      HA
         HAVST     HAVSTD      BNDL      TRNSPT    TRSPTD     THRSH     THRSD
••• ••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••

                     % BROKEN GRAIN =        21.35

DATE =   20    RAIN, NO HARVEST

                     GRAIN MOISTURE%=    23.69
                     SUN CHECKS%=     35.86
                     PRE HARVEST LOSSES(KG/HA)=       9.07
                     TOTAL LOSS PRE HARVEST(KG)=       9.53
                     BIRD & RODENT LOSSES(KG/HA)=      13.24
```

```
                    GRAIN MOISTURE%=   23.66
                    SUN CHECKS%=    39.02
                    PRE HARVEST LOSSES(KG/HA)=      9.74
                    TOTAL LOSS PRE HARVEST(KG)=      9.16
                    BIRD & RODENT LOSSES(KG/HA)=     15.79
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      14.84
                    TOTAL BIRD & RODENT LOSSES(KG)=     14.84

                    % BROKEN GRAIN =       19.99

DATE =   22    RAIN, NO HARVEST

                    GRAIN MOISTURE%=   23.61
                    SUN CHECKS%=    42.18
                    PRE HARVEST LOSSES(KG/HA)=     10.41
                    TOTAL LOSS PRE HARVEST(KG)=      9.79
                    BIRD & RODENT LOSSES(KG/HA)=     18.33
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      17.23
                    TOTAL BIRD & RODENT LOSSES(KG)=     17.23

                    % BROKEN GRAIN =       19.48

DATE =   23    RAIN, NO HARVEST

                    GRAIN MOISTURE%=   23.51
                    SUN CHECKS%=    45.34
                    PRE HARVEST LOSSES(KG/HA)=     11.08
                    TOTAL LOSS PRE HARVEST(KG)=     10.42
                    BIRD & RODENT LOSSES(KG/HA)=     20.87
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      19.61
                    TOTAL BIRD & RODENT LOSSES(KG)=     19.61

                    % BROKEN GRAIN =       19.07

DAY =   24  LABOR =      7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   23.42
                    SUN CHECKS%=    48.50
                    PRE HARVEST LOSSES(KG/HA)=     11.75
                    TOTAL LOSS PRE HARVEST(KG)=     11.04
                    BIRD & RODENT LOSSES(KG/HA)=     23.41
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      22.00
                    TOTAL BIRD & RODENT LOSSES(KG)=     22.00

HARVEST INCOMPLETE

8.05      0.0947      0.8452      0.8452      0.0        0.0        0.0        0.0

                    POST HARVEST LOSSES(KG/HA)=     13.80
                    TOTAL LOSS POST HARVEST(KG)=     11.67

DAY =   25  LABOR =      8          NO RAIN, LABOR    AVAILABLE, HARVEST
```

```
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       2.46
                    TOTAL BIRD & RODENT LOSSES(KG)=      24.46

 HARVEST CCMPLETED

0.80    0.0      0.9400    0.9412    0.0      0.0      0.0      0.0

                    POST HARVEST LOSSES(KG/HA)=      14.93
                    TOTAL LOSS POST HARVEST(KG)=      13.10

                    AREA TO THRESH=        0.0
                    AREA THRESHED=         0.0

 DAY =   26    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS     6  LABOR BUNDLNG IS     5

                    GRAIN MOISTURE%=   23.13
                    SUNCHECK%=     54.82
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      24.46

                    AREA TO THRESH=        0.4493
                    AREA THRESHED=         0.2254

 DAY =   27   ·RAIN, TRANSPORT

      LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     3

                    GRAIN MOISTURE%=   22.94
                    SUNCHECK%=     57.98
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      24.46

 HARVST BNDLNG AND TRNSPT COMPLTE

3.05    0.0      0.9400    0.0      0.0      0.9400    0.4493    0.2254

                    BUNDLING LOSS (KG/HA)=      17.18
                    TOTAL BUNDLING LOSSES(KG)=      15.12
                    TRANSPORT LOSS (KG/HA)=      41.97
                    TOTAL TRANSPORT LOSSES(KG)=      11.11

                    AREA TO THRESH=        0.7141
                    AREA THRESHED=         0.2254

 DAY =   28    NO RAIN THRESH
```

```
LABOR TRANSPRT IS      5  LABOR BUNDLNG IS      4

            GRAIN MOISTURE%=    23.29
            SUNCHECK%=     51.66
            BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=        0.0
            TOTAL BIRD AND RODENT LOSSES(KG)=      22.00

            AREA TO THRESH=         0.3360
            AREA THRESHED=         0.2254

DAY =   26    NO RAIN, TRANSPORT & THRESH

LABOR TRANSPRT IS      5  LABOR BUNDLNG IS      4

            GRAIN MOISTURE%=    23.13
            SUNCHECK%=     54.82
            BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=        0.0
            TOTAL BIRD AND RODENT LOSSES(KG)=      22.00

            AREA TO THRESH=         0.4817
            AREA THRESHED=         0.4508

DAY =   27    NO RAIN, TRANSPORT & THRESH

LABOR TRANSPRT IS      3  LABOR BUNDLNG IS      2

            GRAIN MOISTURE%=    22.94
            SUNCHECK%=     57.98
            BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=        0.0
            TOTAL BIRD AND RODENT LOSSES(KG)=      22.00

            AREA TO THRESH=         0.2563
            AREA THRESHED=         0.6762

DAY =   28    RAIN, TRANSPORT

LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4

            GRAIN MOISTURE%=    22.73
            SUNCHECK%=     61.14
            BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=        0.0
            TOTAL BIRD AND RODENT LOSSES(KG)=      22.00

HARVST BNDLNG AND TRNSPT COMPLTE

0.05     0.0      0.9400     0.0      0.0      0.9400     0.2563     0.6762
```

```
                    AREA TO THRESH=        0.2632
                    AREA THRESHED=        0.6762

DAY =   30    NO RAIN THRESH

                    AREA TO THRESH=        0.0378
                    AREA THRESHED=        0.9016

DAY =   31    NO RAIN THRESH

THRESHING COMPLETE

1.40    0.0     0.9400    0.0      0.0      0.9400    0.0      0.9408

                    TOTAL PRE HARVEST LOSSES(KG)=      12.22
                    TOTAL POSTHARVEST LOSSES(KG)=      13.10
                    TOTAL BIRD AND RODENT LOSSES(KG)=      24.46
                    TOTAL BUNDLING LOSSES(KG)=      15.12
                    TOTAL TRANSPORTATION LOSSES(KG)=      11.11
                    TOTAL GRAIN LOSSES(KG)=      76.01

                    TOTAL LABOR USED=          53
****************************************************************************************************************

TIME     HA TO      HA       HA TO     HA TO      HA       HA TO      HA
         HAVST    HAVSTD     BNDL     TRNSPT    TRSPTD     THRSH     THRSD
***  ****************************************************************

                    % BROKEN GRAIN =       19.07

DAY =   24  LABOR =     9        NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=    23.42
                    SUN CHECKS%=     48.50
                    PRE HARVEST LOSSES(KG/HA)=      11.75
                    TOTAL LOSS PRE HARVEST(KG)=      11.04
                    BIRD & RODENT LOSSES(KG/HA)=      23.41
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      22.00
                    TOTAL BIRD & RODENT LOSSES(KG)=      22.00

HARVEST COMPLETED

7.00    0.0     0.9400    0.9450    0.0      0.0      0.0      0.0

                    POST HARVEST LOSSES(KG/HA)=      13.80
                    TOTAL LOSS POST HARVEST(KG)=      13.04
```

```
                    AREA TO THRESH=        0.2619
                    AREA THRESHED=        0.6762

 DAY =   29    NO RAIN THRESH

                    AREA TO THRESH=        0.0364
                    AREA THRESHED=        0.9016

 DAY =   30    NO RAIN THRESH

 THRESHING COMPLETE

1.35     0.0       0.9400     0.0       0.0       0.9400     0.0       0.9394

                    TOTAL PRE HARVEST LOSSES(KG)=      11.34
                    TOTAL POSTHARVEST LOSSES(KG)=      13.04
                    TOTAL BIRD AND RODENT LOSSES(KG)=      22.00
                    TOTAL BUNDLING LOSSES(KG)=      14.25
                    TOTAL TRANSPORTATION LOSSES(KG)=      0.25
                    TOTAL GRAIN LOSSES(KG)=      60.58

                    TOTAL LABOR USED=           60
********************** ************************************************************ *********************

TIME     HA TO      HA       HA TO      HA TO      HA       HA TO      HA
       HAVST     HAVSTD      HNDL      TRNSPT     TRSPTD     THRSH     THRSD
*** ***********************************************************

                    % BROKEN GRAIN =       18.54

 DAY =   28  LABOR =      9          NO RAIN. LABOR    AVAILABLE. HARVEST

                    GRAIN MOISTURE%=   22.73
                    SUN CHECKS%=    61.14
                    PRE HARVEST LOSSES(KG/HA)=      14.43
                    TOTAL LOSS PRE HARVEST(KG)=      13.56
                    BIRD & RODENT LOSSES(KG/HA)=      33.57
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      31.55
                    TOTAL BIRD & RODENT LOSSES(KG)=      31.55

 HARVEST COMPLETED

7.00     0.0       0.9400     0.9450     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      18.30
                    TOTAL LOSS POST HARVEST(KG)=      17.29
```

```
     LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=   22.49
                    SUNCHECK%=     64.30
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      31.55

                    AREA TO THRESH=         0.2244
                    AREA THRESHED=         0.2254

DAY =   30    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=   22.23
                    SUNCHECK%=     67.46
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      31.55

                    AREA TO THRESH=         0.4852
                    AREA THRESHED=         0.4538

DAY =   31    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS      5  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=   21.93
                    SUNCHECK%=     70.62
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      31.55

                    AREA TO THRESH=         0.2598
                    AREA THRESHED=         0.6762

DAY =   32    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS      3  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=   21.62
                    SUNCHECK%=     73.79
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      31.55

                    AREA TO THRESH=         0.0343
                    AREA THRESHED=         0.9316

DAY =   33    NO RAIN, TRANSPORT & THRESH
```

```
HAVST.BUND.TRANS.THRESH COMPLETE

1.25     0.0       0.9400     0.0       0.0       0.0       0.0       0.0366

                    BUNDLING LOSS (KG/HA)=      23.92
                    TOTAL BUNDLING LOSSES(KG)=      18.46

                    TOTAL PRE HARVEST LOSSES(KG)=      13.56
                    TOTAL POSTHARVEST LOSSES(KG)=      17.29
                    TOTAL BIRD AND RODENT LOSSES(KG)=      31.55
                    TOTAL BUNDLING LOSSES(KG)=      18.46
                    TOTAL TRANSPORTATION LOSSES(KG)=      0.0
                    TOTAL GRAIN LOSSES(KG)=      80.87

                    TOTAL LABOR USED=          64
*********************** ****************************************************************** ***********************

TIME     HA TO      HA        HA TO      HA TO      HA        HA TO      HA
         HAVST      HAVSTD    BNDL       TRNSPT     TRSPTD    THRSH      THRSD
*** ***********************************************************

                    % BROKEN GRAIN =       19.76

  DAY =   32  LABOR =     7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   21.62
                    SUN CHECKS%=    73.79
                    PRE HARVEST LOSSES(KG/HA)=      17.10
                    TOTAL LOSS PRE HARVEST(KG)=      16.08
                    BIRD & RODENT LOSSES(KG/HA)=      43.73
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      41.10
                    TOTAL BIRD & RODENT LOSSES(KG)=      41.10

  HARVEST INCOMPLETE

8.35     0.3947    0.8452     0.8452     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      22.80
                    TOTAL LOSS POST HARVEST(KG)=      19.27

  DAY =   33    RAIN TRANSPORT ON

                    GRAIN MOISTURE%=   21.27
                    SUN CHECKS%=    76.95
                    PRE HARVEST LOSSES(KG/HA)=      17.77
                    TOTAL LOSS PRE HARVEST(KG)=      17.76
                    BIRD & RODENT LOSSES(KG/HA)=      46.27
```

```
DAY =   34    RAIN TRANSPORT DH

                     GRAIN MOISTURE X=   20.90
                     SUN CHECKSX=    80.11
                     PRE HARVEST LOSSES(KG/HA)=      18.44
                     TOTAL LOSS PRE HARVEST(KG)=      19.51
                     BIRD & RODENT LOSSES(KG/HA)=      48.81
                     BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       4.62
                     TOTAL BIRD & RODENT LOSSES(KG)=      50.11

      LABOR TRANSPORT IS      4  LABOR BUNDLNG IS      3

 BUND AND TRANS OF DH COMPLETE

4.95     0.0947     0.8452     0.0       0.0       0.8480     0.0       0.0

                     BUNDLING LOSS (KG/HA)=      25.05
                     TOTAL BUNDLING LOSSES(KG)=      21.34
                     TRANSPORT LOSS (KG/HA)=      58.87
                     TOTAL TRANSPORT LOSSES(KG)=      49.83

                     % BROKEN GRAIN =        21.82
DAY =   35  LABOR =      9          NO RAIN, LABOR    AVAILABLE, HARVEST

                     GRAIN MOISTURE X=   22.51
                     SUN CHECKSX=    83.27
                     PRE HARVEST LOSSES(KG/HA)=      19.11
                     TOTAL LOSS PRE HARVEST(KG)=      21.32
                     BIRD & RODENT LOSSES(KG/HA)=      51.35
                     BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       4.87
                     TOTAL BIRD & RODENT LOSSES(KG)=      54.98

HARVEST COMPLETED

0.83     0.0     0.9433     0.0960     0.0       0.8480     0.0       0.0

                     POST HARVEST LOSSES(KG/HA)=      26.17
                     TOTAL LOSS POST HARVEST(KG)=      21.78

                     AREA TO THRESH=        0.8480
                     AREA THRESHED=        0.0

DAY =   36    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPORT IS      3  LABOR BUNDLNG IS      2

                     GRAIN MOISTURE X=   23.08
                     SUNCHECKX=    86.43
                     BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
```

```
DAY =   37    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=    19.63
                    SUNCHECK%=     89.59
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      54.98

                    AREA TO THRESH=         0.4907
                    AREA THRESHED=         0.4508

DAY =   38    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      3  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=    19.16
                    SUNCHECK%=     92.75
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      54.98

                    AREA TO THRESH=         0.2653
                    AREA THRESHED=         0.6762

DAY =   39    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      6  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=    18.65
                    SUNCHECK%=     95.91
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      54.98

                    AREA TO THRESH=         0.0399
                    AREA THRESHED=         0.9016

DAY =   40    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      2  LABOR BUNDLNG IS      2

                    GRAIN MOISTURE%=    18.13
                    SUNCHECK%=     99.07
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      54.98

 HAVST,BUND,TRANS,THRESH COMPLETE

1.45      0.0        0.9400      0.0        0.0        0.0        0.0        0.9422
```

```
                    TOTAL BIRD AND RODENT LOSSES(KG)=      54.98
                    TOTAL BUNDLING LOSSES(KG)=      22.92
                    TOTAL TRANSPORTATION LOSSES(KG)=      48.83
                    TOTAL GRAIN LOSSES(KG)=     169.83

                    TOTAL LABOR USED=           82

*********************** ****************************************************************** ***********************


 TIME      HA TO       HA        HA TO      HA TO       HA        HA TO      HA
         HAVST      HAVSTD      BNDL      TRNSPT     TRSPTD      THRSH     THRSD
*** ************************************************************


                    % BROKEN GRAIN =        22.73

  DAY =    36  LABOR =      9           NO RAIN, LABOR    AVAILABLE, HARVEST


                    GRAIN MOISTURE%=   20.08
                    SUN CHECKS%=    86.43
                    PRE HARVEST LOSSES(KG/HA)=      19.78
                    TOTAL LOSS PRE HARVEST(KG)=      18.59
                    BIRD & RODENT LOSSES(KG/HA)=      53.89
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      50.65
                    TOTAL BIRD & RODENT LOSSES(KG)=      53.65

  HARVEST COMPLETED


 7.00     0.0       0.9400     0.9450     0.0        0.0        0.0        0.0


                    POST HARVEST LOSSES(KG/HA)=      27.30
                    TOTAL LOSS POST HARVEST(KG)=      25.83

                    AREA TO THRESH=        0.0
                    AREA THRESHED=         0.0


  DAY =    37    NO RAIN, TRANSPORT & THRESH

       LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=   19.63
                    SUNCHECK%=     89.59
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      53.65

                    AREA TO THRESH=        0.2244
                    AREA THRESHED=         0.2254


  DAY =    38    NO RAIN, TRANSPORT & THRESH
```

```
                SUNCHECK%=    92.75
                BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                TOTAL BIRD AND RODENT LOSSES(KG)=     50.65

                AREA TO THRESH=        0.4824
                AREA THRESHED=        0.4508

DAY =   39    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     3

                GRAIN MOISTURE%=   18.65
                SUNCHECK%=    95.91
                BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                TOTAL BIRD AND RODENT LOSSES(KG)=     50.65

                AREA TO THRESH=        0.2570
                AREA THRESHED=        0.6762

DAY =   40    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS     6  LABOR BUNDLNG IS     4

                GRAIN MOISTURE%=   18.13
                SUNCHECK%=    99.07
                BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                TOTAL BIRD AND RODENT LOSSES(KG)=     50.65

                AREA TO THRESH=        0.0316
                AREA THRESHED=        0.9016

DAY =   41    NO RAIN, TRANSPORT & THRESH

     LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     4

                GRAIN MOISTURE%=   17.57
                SUNCHECK%=   102.23
                BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                TOTAL BIRD AND RODENT LOSSES(KG)=     50.65
 HAVST,BUND,TRANS,THRESH COMPLETE

1.15     0.0       0.9400     0.0       0.0       0.0       0.0       0.9338

                BUNDLING LOSS (KG/HA)=     32.92
                TOTAL BUNDLING LOSSES(KG)=     27.06

                TOTAL PRE HARVEST LOSSES(KG)=     18.59
```

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*********************** ************************************************************ ***********************

TIME     HA TO       HA        HA TO      HA TO       HA        HA TO       HA
         HAVST     HAVSTD      BNDL       TRNSPT     TRSPTD     THRSH      THRSD
*** ************************************************************

                      % BROKEN GRAIN =        27.45

  DAY =   40  LABOR =     5          NO RAIN, LABOR    AVAILABLE, HARVEST

                      GRAIN MOISTURE%=   19.13
                      SUN CHECKS%=     99.37
                      PRE HARVEST LOSSES(KG/HA)=      22.46
                      TOTAL LOSS PRE HARVEST(KG)=      21.11
                      BIRD & RODENT LOSSES(KG/HA)=      64.05
                      BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      60.21
                      TOTAL BIRD & RODENT LOSSES(KG)=      60.21

  HARVEST INCOMPLETE

8.05     0.3362     0.6037     0.6037     0.0       0.0       0.0       0.0

                      POST HARVEST LOSSES(KG/HA)=      31.79
                      TOTAL LOSS POST HARVEST(KG)=      19.23

  DAY =   41    RAIN TRANSPORT DH

                      GRAIN MOISTURE%=   17.57
                      SUN CHECKS%=    132.23
                      PRE HARVEST LOSSES(KG/HA)=      23.13
                      TOTAL LOSS PRE HARVEST(KG)=      28.89
                      BIRD & RODENT LOSSES(KG/HA)=      66.59
                      BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      22.39
                      TOTAL BIRD & RODENT LOSSES(KG)=      82.60

       LABOR TRANSPRT IS     6  LABOR BUNDLNG IS     5

   BUND AND TRANS OF DH COMPLETE

6.40     0.3362     0.6037     0.0       0.0       0.6028     0.0       0.0

                      BUNDLING LOSS (KG/HA)=      32.92
                      TOTAL BUNDLING LOSSES(KG)=      19.73
                      TRANSPORT LOSS (KG/HA)=     75.76
                      TOTAL TRANSPORT LOSSES(KG)=      45.67

                      % BROKEN GRAIN =        33.46

  DATE =   42    RAIN, NO HARVEST
```

```
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      23.25
                TOTAL BIRD & RODENT LOSSES(KG)=     105.84

                % BROKEN GRAIN =        32.13

DATE =    43    RAIN, NO HARVEST


                GRAIN MOISTURE%=    16.38
                SUN CHECKS%=    108.55
                PRE HARVEST LOSSES(KG/HA)=      24.47
                TOTAL LOSS PRE HARVEST(KG)=      8.23
                BIRD & RODENT LOSSES(KG/HA)=     71.67
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      24.10
                TOTAL BIRD & RODENT LOSSES(KG)=      24.10

                % BROKEN GRAIN =        33.91

DATE =    44    RAIN, NO HARVEST


                GRAIN MOISTURE%=    15.75
                SUN CHECKS%=    111.71
                PRE HARVEST LOSSES(KG/HA)=      25.13
                TOTAL LOSS PRE HARVEST(KG)=      8.45
                BIRD & RODENT LOSSES(KG/HA)=     74.21
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      24.95
                TOTAL BIRD & RODENT LOSSES(KG)=      24.95

                % BROKEN GRAIN =        35.80

DATE =    45    RAIN, NO HARVEST


                GRAIN MOISTURE%=    15.09
                SUN CHECKS%=    114.87
                PRE HARVEST LOSSES(KG/HA)=      25.80
                TOTAL LOSS PRE HARVEST(KG)=      8.68
                BIRD & RODENT LOSSES(KG/HA)=     76.75
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      25.81
                TOTAL BIRD & RODENT LOSSES(KG)=      25.81

                % BROKEN GRAIN =        37.80

DATE =    46    RAIN, NO HARVEST


                GRAIN MOISTURE%=    14.41
                SUN CHECKS%=    118.04
                PRE HARVEST LOSSES(KG/HA)=      26.47
                TOTAL LOSS PRE HARVEST(KG)=      8.90
                BIRD & RODENT LOSSES(KG/HA)=     79.29
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      26.66
                TOTAL BIRD & RODENT LOSSES(KG)=      26.66

                % BROKEN GRAIN =        39.91

DATE =    47    RAIN, NO HARVEST
```

```
                  % BROKEN GRAIN =        42.13

DAY =   48  LABOR =      6          NO RAIN, LABOR    AVAILABLE, HARVEST

                  GRAIN MOISTURE%=    12.95
                  SUN CHECKS%=    124.36
                  PRE HARVEST LOSSES(KG/HA)=      27.81
                  TOTAL LOSS PRE HARVEST(KG)=       9.35
                  BIRD & RODENT LOSSES(KG/HA)=      84.37
                  BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      28.37
                  TOTAL BIRD & RODENT LOSSES(KG)=      28.37

HARVEST COMPLETED

1.75     0.0        0.0400     0.3375     0.0        0.6028     0.0        0.0

                  POST HARVEST LOSSES(KG/HA)=      40.79
                  TOTAL LOSS POST HARVEST(KG)=      32.96

                  AREA TO THRESH=         0.6028
                  AREA THRESHED=         0.0

DAY =   49    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      5  LABOR BUNDLNG IS      4

                  GRAIN MOISTURE%=    12.18
                  SUNCHECK%=    127.52
                  BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                  TOTAL BIRD AND RODENT LOSSES(KG)=      28.37

                  AREA TO THRESH=         0.7057
                  AREA THRESHED=         0.2254

DAY =   50    NO RAIN, TRANSPORT & THRESH

      LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4

                  GRAIN MOISTURE%=    11.39
                  SUNCHECK%=    130.68
                  BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=      0.0
                  TOTAL BIRD AND RODENT LOSSES(KG)=      28.37

                  AREA TO THRESH=         0.4803
                  AREA THRESHED=         0.4508

DAY =   51    NO RAIN, TRANSPORT & THRESH
```

```
                    SUNCHECK%=   133.84
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      28.37

                    AREA TO THRESH=         0.2549
                    AREA THRESHED=         0.6762

 DAY =   52    NO RAIN, TRANSPORT & THRESH

       LABOR TRANSPRT IS      6  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=     9.73
                    SUNCHECK%=   127.00
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      28.37

                    AREA TO THRESH=         0.0295
                    AREA THRESHED=         0.9016

 DAY =   53    NO RAIN, TRANSPORT & THRESH

       LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=     8.85
                    SUNCHECK%=   140.16
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=      28.37

  HAVST.BUND.TRANS.THRESH COMPPLETE

1.10     0.0       0.9400     0.0       0.0       0.0       0.0       0.9324

                    BUNDLING LOSS (KG/HA)=      46.41
                    TOTAL BUNDLING LOSSES(KG)=      33.75

                    TOTAL PRE HARVEST LOSSES(KG)=       9.35
                    TOTAL POSTHARVEST LOSSES(KG)=      32.96
                    TOTAL BIRD AND RODENT LOSSES(KG)=      28.37
                    TOTAL BUNDLING LOSSES(KG)=      33.75
                    TOTAL TRANSPORTATION LOSSES(KG)=      45.67
                    TOTAL GRAIN LOSSES(KG)=    150.10

                    TOTAL LABOR USED=           82
******************** ****************************************************** **********************
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APPENDIX All

Tractor Threshing

and

Results

Transport Model Card 113-176

Tractor Model Card 177-203

```
      A=DH-PNDT
      IF(H.LT.0.0)  H=0.0
      IF(H.EQ.0.0)  DH=PLAND
      IF(H.LQ.0.0)  GO TO 11
      IF((R.0)-T).LT..0001)  GO TO 35
   10 CONTINUE
   11 PRINT 12
   12 FORMAT(4X,'HARVEST COMPLETED'//)
      PRINT  9,T,H,DH,A,AT,ATR,APT,ATT
    9 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,PSVT
  151 FORMAT(25X,'POST HARVEST LOSSES(KG/HA)=', 2X,F8.2/
     6                                          25X,'TOTAL LOSS POST HARVEST(K
     7G)=',2X,F8.2/)
      A=DH-BNDT
      APT=ATR
   13 CONTINUE
C-
C-****************************************************************************
      T=0.0
      N=N+1
C-****************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                             11-11
      SNC=-27.357+3.1607*N                                               11-11
      BRD=-37.559+2.5402*N                                               11-11
C-****************************************************************************
      TBRD=BRD*(RLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      PRINT 81,N
   81 FORMAT(4X,'DAY  =',2X,I3,4X,'BUNDLING AND TRANSPORT'//)
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TP=X/D*1/2*B
      BR=0.022
  101 CONTINUE
      TRR=TR*LABT
      BRR=BR*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 101
      PRINT 62,LABT,LABB
   62 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     8I4,//)
      PRT=TRR
      LABTOT=LABTOT+LAB
      PRINT 152,GAV,SNC,TBRD,BRDT
  152 FORMAT(25X,'GRAIN MOISTURE%=',2X,F6.2/25X,'SUNCHECK%=',2X,F7.2/25X
     8,'BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=',2X,F8.2/25X,'TOTAL BI
     9RD AND RODENT LOSSES(KG)=',2X,F8.2/)
      DO 15 IJ=1,NN
      T=T+DT
      A=A-BR2*DT
      IF(A.GT.0)  GO TO 16
```

```
      A=0.0
      BN=0.
      HPR=0.
      LABRT=LABT+LABR
      TPR=TP*LABRT
   16 CONTINUE
      BN=BPR*DT
      AT=AT+BN-TPR*DT
      ATR=ATR+TPR*DT
      SI=SI+TPR*DT
      IF(AT.LT.0.0)    AT=0.0
      IF(AT.EQ.0.0)   ATR=DH
      BND=BND+BRT*DT
      IF(A.EQ.0.0)   BND=DH
      IF(A.EQ.0.0)    BNDT=BND
C-*****************************************************************************
      BNDL=-13.109+1.1246*N                                                 11-11
      TRL=-23.206+2.4139*N                                                  11-11
C-*****************************************************************************
      TBNDL=BNDL*BN
      BNDLT=BNDLT+TBNDL
      TTPL=TPL*TPR*DT
      TRLT=TRLT+TTRL
      IF(AT.EQ.0.0)   GO TO 18
      IF((8.00-T).LT..001)   GO TO 13
   15 CONTINUE
   18 PRINT 19
   19 FORMAT(5X,'HARVST BNDLNG AND TRNSPT COMPLTE'//)
      PRINT 17,T,H,DH,A,AT,ATR,APT,ATT
   17 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     1F7.4//)
      PRINT 153,BNDL,      BNDLT,TRL,      TRLT
  153 FORMAT(25X,'BUNDLING LOSS (KG/HA)=',2X,F8.2/
     1                     25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/25X
     2,'TRANSPORT LOSS (KG/HA)=',2X,F8.2/
     3                25X,'TOTAL TRANSPORT LOSSES(KG)=',2X,F8.2/)
C-*****************************************************************************
      APT=ATR                                                           TRACTOR
      GO TO 120
  121 PRINT 122,N
  122 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN NO TRACTOR THRESHING'//)
  120 PRINT 170,APT,ATT
  170 FORMAT(25X,'AREA TO THRESH=',5X,F9.4/25X,'AREA THRESHED=',5X,F9.4/
     6/)
      N=N+1
      M=M+1
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.1)   GO TO 121
      LABTOT=LABTOT+LABTR
      PRINT 123,N
  123 FORMAT(4X,'DAY =',2X,I3,4X,'NO RAIN THRESH WITH TRACTOR'//)
      T=0.0
      DO 124 II=1,NN
      T=T+DT
      APT=APT-TRAC*DT
      ATT=ATT+TRAC*DT
      IF(APT.LT.0.0)    APT=0.0
      IF(APT.EQ.0.0)   GO TO 126
```

```
      IF((8.00-T).LT..001)  GO TO 12)
  124 CONTINUE
  126 PRINT 127
  127 FORMAT(4X,'THRESHING COMPLETE'//)
      PRINT 125,T,H,DH,A,AT,ATR,APT,ATT
  125 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     2F7.4//)
      GO TO 55
C-*****************************************************************************
   25 PRINT 36
   36 FORMAT(4X,'HARVEST INCOMPLETE'//)
      PRINT 79,T,H,DH,A,AT,ATR,APT,ATT
   79 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,      PSVT
      A=DH-UNDT
   37 CONTINUE
      T=0.0
   63 N=N+1
C- ****************************************************************************
      GAV=18.71+0.51263*N-0.13181F-01*(N**2)                          11-11
      SNC=-27.357+3.1607*N                                            11-11
      BRD=-37.559+2.5402*N
      PHV=-4.3123+0.60924*N
C-*****************************************************************************
      TPHV=PHV*(RLAND-DH)
      PHVT=PHVT+TPHV
      TBRD=BRD*(RLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      CALL LABOR(LI)
      LABH=LABF+LI
      IF(LABH.LT.5)  PRINT 60
   60 FORMAT(10X,'NO LABOR FOR HARVEST'//)
      IF(LABH.LT.5)  GO TO 63
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.0)  GO TO 8
      PRINT 38,N
   38 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN TRANSPORT DH'//)
      PRINT 150,GAV,SNC,PHV,      PHVT,BRD,TBRD,BRDT
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D*1/2*B
      UR=0.022
  102 CONTINUE
      THR=TR*LABT
      BRR=UR*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 102
      PRINT 66,LABT,LABB
   66 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     5I4,//)
      LABTOT=LABTOT+LAB
      PRT=BRR
```

```
                    AREA TC THRESH=        0.1400
                    AREA THRESHED=        0.8000

  DAY =   38    NO RAIN THRESH WITH TRACTOR

  THRESHING COMPLETE

1.40     0.0       0.9400     0.0       0.0       0.9400     0.0       0.9400

                    TOTAL PRE HARVEST LOSSES(KG)=      16.08
                    TOTAL POSTHARVEST LOSSES(KG)=      21.48
                    TOTAL BIRD AND RODENT LOSSES(KG)=      41.19
                    TOTAL BUNDLING LOSSES(KG)=     22.71
                    TOTAL TRANSPORTATION LOSSES(KG)=      54.12
                    TOTAL GRAIN LOSSES(KG)=     155.48

                    TOTAL LABOR USED=           31
*********************** ************************************************************ ***********************

TIME     HA TO      HA       HA TO     HA TO      HA       HA TO      HA
         HAVST     HAVSTD     BNDL     TRNSPT    TRSPTD     THRSH     THRSD
*** ************************************************************

                    % BROKEN GRAIN =       34.32

  DATE =   36    RAIN, NO HARVEST

                    GRAIN MOISTURE%=   20.08
                    SUN CHECKS%=    86.43
                    PRE HARVEST LOSSES(KG/HA)=      19.78
                    TOTAL LOSS PRE HARVEST(KG)=      18.59
                    BIRD & RODENT LOSSES(KG/HA)=      53.89
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      50.65
                    TOTAL BIRD & RODENT LOSSES(KG)=      50.65

                    % BROKEN GRAIN =       35.51

  DATE =   37    RAIN, NO HARVEST

                    GRAIN MOISTURE%=   19.63
                    SUN CHECKS%=    89.59
                    PRE HARVEST LOSSES(KG/HA)=      20.45
                    TOTAL LOSS PRE HARVEST(KG)=      19.22
                    BIRD & RODENT LOSSES(KG/HA)=      56.43
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      53.04
                    TOTAL BIRD & RODENT LOSSES(KG)=      53.04

                    % BROKEN GRAIN =       36.84
```

```
DAY =   39  LABOR =      7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   18.65
                    SUN CHECKS%=     95.91
                    PRE HARVEST LOSSES(KG/HA)=      21.79
                    TOTAL LOSS PRE HARVEST(KG)=      40.33
                    BIRD & RODENT LOSSES(KG/HA)=      61.51
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      57.82
                    TOTAL BIRD & RODENT LOSSES(KG)=     113.25

HARVEST INCOMPLETE

8.05     0.0947     0.8452     0.8452     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      30.67
                    TOTAL LOSS POST HARVEST(KG)=      25.92

DAY =   40  LABOR =      6          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   18.13
                    SUN CHECKS%=     99.07
                    PRE HARVEST LOSSES(KG/HA)=      22.46
                    TOTAL LOSS PRE HARVEST(KG)=      42.46
                    BIRD & RODENT LOSSES(KG/HA)=      64.35
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       6.07
                    TOTAL BIRD & RODENT LOSSES(KG)=     119.32

HARVEST COMPLETED

1.19     0.0        0.9430     0.9442     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      31.79
                    TOTAL LOSS POST HARVEST(KG)=      29.07

DAY  =   41    BUNDLING AND TRANSPORT

      LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4

                    GRAIN MOISTURE%=   17.57
                    SUNCHECK%=    102.23
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=     119.32

DAY  =   42    BUNDLING AND TRANSPORT

      LABOR TRANSPRT IS      3  LABOR BUNDLNG IS      3

                    GRAIN MOISTURE%=   16.99
                    SUNCHECK%=    105.39
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
```

```
                    BUNDLING LOSS (KG/HA)=      34.04
                    TOTAL BUNDLING LOSSES(KG)=      31.15
                    TRANSPORT LOSS (KG/HA)=      78.10
                    TOTAL TRANSPORT LOSSES(KG)=      72.37

                    AREA TC THRESH=        0.9400
                    AREA THRESHED=        0.0

 DAY =   43    NO RAIN THRESH WITH TRACTOR

                    AREA TC THRESH=        0.1400
                    AREA THRESHED=        0.8000

 DAY =   44    NO RAIN THRESH WITH TRACTOR

 THRESHING COMPLETE

1.40     0.0        0.9400     0.0        0.0        0.9400     0.0        0.9400

                    TOTAL PRE HARVEST LOSSES(KG)=      42.46
                    TOTAL POSTHARVEST LOSSES(KG)=      29.07
                    TOTAL BIRD AND RODENT LOSSES(KG)=     119.32
                    TOTAL BUNDLING LOSSES(KG)=      31.15
                    TOTAL TRANSPORTATION LOSSES(KG)=      72.37
                    TOTAL GRAIN LOSSES(KG)=     294.36

                    TOTAL LABOR USED=           35
************************ ********************************************************************* ***********************

TIME      HA TO       HA         HA TO      HA TO       HA         HA TO       HA
         HAVST      HAVSTD       ANDL       TRNSPT      TRSPTD      THRSH       THRSD
*** ************************************************************

                    % BROKEN GRAIN =        39.93

 DAY =   40  LABOR =      7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=    18.13
                    SUN CHECKS%=     99.97
                    PRE HARVEST LOSSES(KG/HA)=      22.46
                    TOTAL LOSS PRE HARVEST(KG)=      21.11
                    BIRD & RODENT LOSSES(KG/HA)=      64.05
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      60.21
                    TOTAL BIRD & RODENT LOSSES(KG)=      60.21

 HARVEST INCOMPLETE
```

APPENDIX A12

Mechanical Threshing

and

Results

Transport Model Card 113-176

Mechanical Model Card 177-198

```
      A=DH-BNDT
      IF(H.LT.0.0) H=0.0
      IF(H.EQ.0.0) DH=PLAND
      IF(H.EQ.0.0) GO TO 11
      IF((H.00-T).LT..0001) GO TO 35
   10 CONTINUE
   11 PRINT 12
   12 FORMAT(4X,'HARVEST COMPLETED'//)
      PRINT 9,T,H,DH,A,AT,ATP,APT,ATT
    9 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,PSVT
  151 FORMAT(25X,'POST HARVEST LOSSES(KG/HA)=', 2X,F8.2/
     6                                       25X,'TOTAL LOSS POST HARVEST(K
     7G)=',2X,F8.2/)
      A=DH-BNDT
      APT=ATP
   13 CONTINUE
C-
C-*************************************************************************
      T=0.0
      N=N+1
C-*************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                          11-11
      SNC=-27.357+3.1607*N                                            11-11
      BRD=-37.559+2.5402*N                                            11-11
C-*************************************************************************
      THRD=BRD*(PLAND-DH)
      BRDT=BRDT+THRD
      M=M+1
      PRINT 81,N
   81 FORMAT(4X,'DAY  =',2X,I3,4X,'BUNDLING AND TRANSPORT'//)
      CALL LABOR(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D*1/208
      BR=0.022
  101 CONTINUE
      TPR=TR*LABT
      BRR=BR*LABB
      IF(TPR.GT.BRR) LABT=LABT-1
      IF(TPR.GT.BRR) LABB=LABB+1
      IF(TPR.GT.BRR) GO TO 101
      PRINT 62,LABT,LABB
   62 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     8I4,//)
      BPT=BRR
      LABTOT=LABTOT+LAB
      PRINT 152,GAV,SNC,TRPD,BRDT
  152 FORMAT(25X,'GRAIN MOISTURE%=',2X,F6.2/25X,'SUNCHECK%=',2X,F7.2/25X
     8,'BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=',2X,F8.2/25X,'TOTAL BI
     9RD AND RODENT LOSSES(KG)=',2X,F8.2/)
      DO 15 IJ=1,NN
      T=T+DT
      A=A-BRR*DT
      IF(A.GT.0) GO TO 16
```

```
      A=0.0
      BN=0.
      BRR=0.
      LABRT=LABT+LABB
      TRR=TR*LABRT
   16 CONTINUE
      BN=BRR*DT
      AT=AT+BN-TRR*DT
      ATR=ATR+TRR*DT
      SI=SI+TPR*DT
      IF(AT.LT.0.0)    AT=0.0
      IF(AT.EQ.0.0)   ATR=DH
      BND=BND+BRT*DT
      IF(A.EQ.1.0)   BND=DH
      IF(A.EQ.0.0)    BNDT=BND
C-****************************************************************************
      BNDL=-13.189+1.1246*N                                               11-11
      TRL=-23.206+2.4139*N                                                11-11
C-****************************************************************************
      TBNDL=BNDL*HN
      BNDLT=BNDLT+TBNDL
      TTRL=TRL*TRR*DT
      TRLT=TRLT+TTRL
      IF(AT.EQ.0.0)  GO TO 18
      IF((8.00-T).LT..001)  GO TO 13
   15 CONTINUE
   18 PRINT 19
   19 FORMAT(5X,'HARVST BNDLNG AND TRNSPT COMPLTE'//)
      PRINT 17,T,H,DH,A,AT,ATR,APT,ATT
   17 FORMAT(2X,F6.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     1F7.4//)
      PRINT 153,BNDL,       BNDLT,TRL,      TRLT
  153 FORMAT(25X,'BUNDLING LOSS (KG/HA)=',2X,F8.2/
     1                    25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/25X
     2,'TRANSPORT LOSS (KG/HA)=',2X,F8.2/
     3               25X,'TOTAL TRANSPORT LOSSES(KG)=',2X,F8.2/)
C-****************************************************************************
      APT=ATR                                                          MECHANIC
  120 PRINT 170,APT,ATT
  170 FORMAT(25X,'AREA TO THRESH=',5X,F9.4/25X,'AREA THRESHED=',5X,F9.4/
     6)
      N=N+1
      LABTOT=LABTOT+LABM
      M=M+1
      PRINT 80,N
   80 FORMAT(4X,'DAY =',2X,I3,4X,'MECHANICAL THRESHING'//)
      T=0.0
      DO 124 II=1,NN
      T=T+DT
      APT=APT-TM*DT
      ATT=ATT+TM*DT
      IF(APT.LT.0.0)    APT=0.0
      IF(APT.EQ.0.0)  GO TO 126
      IF((8.00-T).LT..001)  GO TO 120
  124 CONTINUE
  126 PRINT 127
  127 FORMAT(4X,'THRESHING COMPLETE'//)
      PRINT 125,T,H,DH,A,AT,ATR,APT,ATT
```

```
  125 FORMAT(2X,F6.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     2F7.4//)
      GO TO 55
C-***************************************************************************
   35 PRINT 36
   36 FORMAT(4X,'HARVEST INCOMPLETE'//)
      PRINT 79,T,H,DH,A,AT,ATR,APT,ATT
   79 FORMAT(2X,F6.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,      PSVT
      A=DH-BRDT
   37 CONTINUE
      T=0.0
   43 N=N+1
C- **************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                            11-11
      SNC=-27.357+3.1607*N                                              11-11
      BRD=-37.559+2.5402*N
      PHV=-4.3123+0.66924*N
C-***************************************************************************
      TPHV=PHV*(PLAND-DH)
      PHVT=PHVT+TPHV
      TBRD=BRD*(PLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      CALL LABOR(LI)
      LABH=LABH+LI
      IF(LABH.LT.5)  PRINT 60
   60 FORMAT(10X,'NO LABOR FOR HARVEST'//)
      IF(LABH.LT.5)  GO TO 43
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.0)  GO TO 8
      PRINT 38,N
   38 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN TRANSPORT DH'//)
      PRINT 152,GAV,SNC,PHV,      PHVT,BRD,TBRD,BRDT
      CALL LABOR(LI)
      LAB=LABH+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.337
      TP=X/D*1/2*B
      BB=0.022
  102 CONTINUE
      TPR=TP*LABT
      BRR=BB*LABB
      IF(TPR.GT.BRR)  LABT=LABT-1
      IF(TPR.GT.BRR)  LABB=LABB+1
      IF(TPR.GT.BRR)  GO TO 102
      PRINT 66,LABT,LABB
   66 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     9I4,//)
      LABTOT=LABTOT+LAB
      RPT=BRR
      DO 39 JJK=1,NN
      T=T+DT
      A=A-BRR*DT
      IF(A.GT.0)  GO TO 40
      DN=0.
```

```
6.00      0.0       0.9400     0.0       0.0       0.9400     0.0       0.9399

                    TOTAL PRE HARVEST LOSSES(KG)=      19.59
                    TOTAL POSTHARVEST LOSSES(KG)=      25.71
                    TOTAL BIRD AND RODENT LOSSES(KG)=      50.65
                    TOTAL BUNDLING LOSSES(KG)=      26.93
                    TOTAL TRANSPORTATION LOSSES(KG)=      63.22
                    TOTAL GRAIN LOSSES(KG)=     185.11

                    TOTAL LABOR USED=           59

*********************** ************************************************************ ***********************

TIME      HA TO      HA        HA TO      HA TO      HA        HA TO      HA
          HAVST      HAVSTD    BNDL       TRNSPT     TRSPTD    THRSH      THRSD
*** ************************************************************

                    % BROKEN GRAIN =        26.13

        NO LABOR FOR HARVEST

                    % BROKEN GRAIN =        27.20

  DAY =   37  LABOR =      7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=    19.63
                    SUN CHECKS%=     89.59
                    PRE HARVEST LOSSES(KG/HA)=      20.45
                    TOTAL LOSS PRE HARVEST(KG)=      37.82
                    BIRD & RODENT LOSSES(KG/HA)=      56.43
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      53.04
                    TOTAL BIRD & RODENT LOSSES(KG)=     103.70

  HARVEST INCOMPLETE

8.05      0.0947    0.8452     0.8452    0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      28.42
                    TOTAL LOSS POST HARVEST(KG)=      24.02

  DAY =   38    RAIN TRANSPORT DH

                    GRAIN MOISTURE%=    19.16
                    SUN CHECKS%=     92.75
                    PRE HARVEST LOSSES(KG/HA)=      21.12
                    TOTAL LOSS PRE HARVEST(KG)=      39.92
                    BIRD & RODENT LOSSES(KG/HA)=      58.97
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       5.59
                    TOTAL BIRD & RODENT LOSSES(KG)=     109.29

        LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      4
```

```
                    PRE HARVEST LOSSES(KG/HA)=      21.79
                    TOTAL LOSS PRE HARVEST(KG)=      41.58
                    BIRD & RODENT LOSSES(KG/HA)=      61.51
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       5.83
                    TOTAL BIRD & RODENT LOSSES(KG)=     115.11

       LABOR TRANSPRT IS      4  LABOR BUNDLNG IS      3

  BUND AND TRANS OF DH COMPLETE

4.95     0.0947     0.8452     0.0       0.0       0.8480     0.0       0.0

                    BUNDLING LOSS (KG/HA)=      30.67
                    TOTAL BUNDLING LOSSES(KG)=      25.08
                    TRANSPORT LOSS (KG/HA)=      70.94
                    TOTAL TRANSPORT LOSSES(KG)=      59.06

                    % BROKEN GRAIN =       31.13

 DAY =   40  LABOR =      8          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   18.13
                    SUN CHECKS%=    99.07
                    PRE HARVEST LOSSES(KG/HA)=      22.46
                    TOTAL LOSS PRE HARVEST(KG)=      44.01
                    BIRD & RODENT LOSSES(KG/HA)=      64.05
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=       6.07
                    TOTAL BIRD & RODENT LOSSES(KG)=     121.18

 HARVEST COMPLETED

0.80     0.0        0.9400     0.0960     0.0       0.8480     0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      31.79
                    TOTAL LOSS POST HARVEST(KG)=      27.07

 DAY  =   41    BUNDLING AND TRANSPORT

       LABOR TRANSPRT IS      3  LABOR BUNDLNG IS      2

                    GRAIN MOISTURE%=   17.57
                    SUNCHECK%=   102.23
                    BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=       0.0
                    TOTAL BIRD AND RODENT LOSSES(KG)=     121.18

  HARVST BNDLNG AND TRNSPT COMPLTE

2.25     0.0        0.9400     0.0       0.0       0.9400     0.8480     0.0
```

```
              AREA THRESHED=        0.0

DAY =   42    MECHANICAL THRESHING

              AREA TO THRESH=        0.8600
              AREA THRESHED=        0.0800

DAY =   43    MECHANICAL THRESHING

              AREA TO THRESH=        0.7800
              AREA THRESHED=        0.1600

DAY =   44    MECHANICAL THRESHING

              AREA TO THRESH=        0.7000
              AREA THRESHED=        0.2400

DAY =   45    MECHANICAL THRESHING

              AREA TO THRESH=        0.6200
              AREA THRESHED=        0.3200

DAY =   46    MECHANICAL THRESHING

              AREA TO THRESH=        0.5400
              AREA THRESHED=        0.4000

DAY =   47    MECHANICAL THRESHING

              AREA TO THRESH=        0.4600
              AREA THRESHED=        0.4800

DAY =   48    MECHANICAL THRESHING

              AREA TO THRESH=        0.3800
              AREA THRESHED=        0.5600

DAY =   49    MECHANICAL THRESHING

              AREA TO THRESH=        0.3000
              AREA THRESHED=        0.6400

DAY =   50    MECHANICAL THRESHING

              AREA TO THRESH=        0.2200
              AREA THRESHED=        0.7200

DAY =   51    MECHANICAL THRESHING

              AREA TO THRESH=        0.1400
```

```
                    AREA THRESHED=        0.8799

 DAY =   53    MECHANICAL THRESHING

 THRESHING COMPLETE

6.00     0.0       0.9400     0.0       0.0       0.9400     0.0       0.9399

                    TOTAL PRE HARVEST LOSSES(KG)=      44.01
                    TOTAL POSTHARVEST LOSSES(KG)=      27.07
                    TOTAL BIRD AND RODENT LOSSES(KG)=     121.18
                    TOTAL BUNDLING LOSSES(KG)=      28.19
                    TOTAL TRANSPORTATION LOSSES(KG)=      66.42
                    TOTAL GRAIN LOSSES(KG)=     286.88

                    TOTAL LABOR USED=           71
*********************** ****************************************************************** **********************

TIME      HA TO      HA       HA TO      HA TO      HA       HA TO      HA
         HAVST     HAVSTD     BNDL      TRNSPT     TRSPTD     THRSH     THRSD
*** ***********************************************************

                    % BROKEN GRAIN =       31.13

 DAY =   40  LABOR =      7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   18.13
                    SUN CHECKS%=    99.07
                    PRE HARVEST LOSSES(KG/HA)=      22.46
                    TOTAL LOSS PRE HARVEST(KG)=      21.11
                    BIRD & RODENT LOSSES(KG/HA)=      64.05
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      60.21
                    TOTAL BIRD & RODENT LOSSES(KG)=      60.21

 HARVEST INCOMPLETE

8.05     0.0947     0.8452     0.8452     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      31.79
                    TOTAL LOSS POST HARVEST(KG)=      26.87

 DAY =   41  LABOR =      6          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   17.57
                    SUN CHECKS%=   102.23
                    PRE HARVEST LOSSES(KG/HA)=      23.13
                    TOTAL LOSS PRE HARVEST(KG)=      23.30
                    BIRD & RODENT LOSSES(KG/HA)=      66.59
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      6.31
```

APPENDIX A13

Buffalo Threshing

and

Results

Transport Model Card 113-176

Buffalo Model Card 177-203

```
      A=DH-BNDT
      IF(H.LT.0.0)  H=0.0
      IF(H.EQ.0.0)  DH=RLAND
      IF(H.EQ.0.0)  GO TO 11
      IF((P.00-T).LT..0001)  GO TO 35
   10 CONTINUE
   11 PRINT 12
   12 FORMAT(4X,'HARVEST COMPLETED'//)
      PRINT  9,T,H,DH,A,AT,ATR,APT,ATT
    9 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,PSVT
  151 FORMAT(25X,'POST HARVEST LOSSES(KG/HA)=', 2X,F8.2/
     6                                    25X,'TOTAL LOSS POST HARVEST(K
     7G)=',2X,F8.2/)
      A=DH-PNDT
      APT=ATR
   13 CONTINUE
C-
C-*****************************************************************************
      T=0.0
      N=N+1
C-*****************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                            11-11
      SNC=-27.357+3.1607*N                                              11-11
      BRD=-37.559+2.5402*N                                              11-11
C-*****************************************************************************
      TBRD=BRD*(FLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      PRINT 81,N
   81 FORMAT(4X,'DAY  =',2X,I3,4X,'BUNDLING AND TRANSPORT'//)
      CALL LABOF(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D+1/2*B
      BF=0.022
  101 CONTINUE
      TRR=TR*LABT
      BRR=BR*LABB
      IF(TRR.GT.BRR)  LABT=LABT-1
      IF(TRR.GT.BRR)  LABB=LABB+1
      IF(TRR.GT.BRR)  GO TO 101
      PRINT 62,LABT,LABB
   62 FORMAT(10X,'LABOR TRANSPRT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     9I4,//)
      BRT=BRR
      LABTOT=LABTOT+LAB
      PRINT 152,GAV,SNC,TBRD,BRDT
  152 FORMAT(25X,'GRAIN MOISTURE%=',2X,F6.2/25X,'SUNCHECK%=',2X,F7.2/25X
     8,'BIRD &  RODENT LOSSES FOR TOTAL AREA(KG)=',2X,F8.2/25X,'TOTAL BI
     9RD AND RODENT LOSSES(KG)=',2X,F8.2/)
      DO 15 IJ=1,NN
      T=T+DT
      A=A-BRR*DT
      IF(A.GT.0)  GO TO 16
```

```
      A=0.0
      BN=0.
      BFF=0.
      LABBT=LABT+LABB
      TPR=TP*LABBT
   16 CONTINUE
      BN=BRF*DT
      AT=AT+BN-TRR*DT
      ATP=ATP+TRR*DT
      SI=SI+TRR*DT
      IF(AT.LT.0.0)   AT=0.0
      IF(AT.EQ.0.0)  ATP=DH
      END=END+BRT*DT
      IF(A.EQ.0.0)  BND=DH
      IF(A.EQ.0.0)   BNDT=BND
C-*******************************************************************************
      BNDL=-13.189+1.1246*N                                                 11-11
      TRL=-23.206+2.4139*N                                                  11-11
C-*******************************************************************************
      TBNDL=BNDL*BN
      BNDLT=BNDLT+TBNDL
      TTRL=TRL*TPR*DT
      TRLT=TRLT+TTRL
      IF(AT.EQ.0.0)  GO TO 18
      IF((8.00-T).LT..001)  GO TO 13
   15 CONTINUE
   18 PRINT 19
   19 FORMAT(5X,'HARVST BNDLNG AND TRNSPT COMPLTE'//)
      PRINT 17,T,M,DH,A,AT,ATG,APT,ATT
   17 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     1F7.4//)
      PRINT 153,BNDL,      BNDLT,TRL,     TRLT
  153 FORMAT(25X,'BUNDLING LOSS (KG/HA)=',2X,F8.2/
     1                      25X,'TOTAL BUNDLING LOSSES(KG)=',2X,F8.2/25X
     2,'TRANSPORT LOSS (KG/HA)=',2X,F8.2/
     3               25X,'TOTAL TRANSPORT LOSSES(KG)=',2X,F8.2/)
C-*******************************************************************************
      APT=ATR                                                            BUFFALO
      GO TO 120
  121 PRINT 122,N
  122 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN NO THRESHING'//)
  120 PRINT 170,APT,ATT
  170 FORMAT(25X,'AREA TO THRESH=',5X,F9.4/25X,'AREA THRESHED=',5X,F9.4/
     6/)
      N=N+1
      M=M+1
      CALL RAIN(J,M,WK11,300)
      IF(J.EQ.1)  GO TO 121
      LABTOT=LABTOT+LABBF
      PRINT 123,N
  123 FORMAT(4X,'DAY =',2X,I3,4X,'NO RAIN THRESH'//)
      T=0.0
      DO 124 II=1,NN
      T=T+DT
      APT=APT-TRTB*DT
      ATT=ATT+TRTH*DT
      IF(APT.LT.0.0)   APT=0.0
      IF(APT.EQ.0.0)  GO TO 126
```

```
      IF((8.00-T).LT..001)  GO TO 120
  124 CONTINUE
  126 PRINT 127
  127 FORMAT(4X,'THRESHING COMPLETE'//)
      PRINT 125,T,H,DH,A,AT,ATR,APT,ATT
  125 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     2F7.4//)
      GO TO 55
C-*****************************************************************************
C-*****************************************************************************
   35 PRINT 36
   36 FORMAT(4X,'HARVEST INCOMPLETE'//)
      PRINT 79,T,H,DH,A,AT,ATR,APT,ATT
   79 FORMAT(2X,F4.2,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,F7.4,4X,
     5F7.4//)
      PRINT 151,PSV,      PSVT
      A=DH-BNDT
   37 CONTINUE
      T=0.0
   63 N=N+1
C- ****************************************************************************
      GAV=18.71+0.51263*N-0.13181E-01*(N**2)                              11-11
      SNC=-27.357+J.1607*N                                                11-11
      HFD=-37.559+2.5402*N
      PHV=-4.3123+0.66924*N
C-*****************************************************************************
      TPHV=PHV*(RLAND-DH)
      PHVT=PHVT+TPHV
      TBRD=BRD*(RLAND-DH)
      BRDT=BRDT+TBRD
      M=M+1
      CALL LABOF(LI)
      LABH=LABF+LI
      IF(LABH.LT.5)  PRINT 60
   60 FORMAT(10X,'NC LABOR FOR HARVEST'//)
      IF(LABH.LT.5)  GO TO 63
      CALL FAIN(J,M,WK11,300)
      IF(J.EQ.0)  GO TO 8
      PRINT 38,N
   38 FORMAT(4X,'DAY =',2X,I3,4X,'RAIN TRANSPORT DH'//)
      PRINT 150,GAV,SNC,PHV,      PHVT,BRD,TBRD,BRDT
      CALL LABOF(LI)
      LAB=LABF+LI
      LABT=2*LAB/3
      LABB=LAB-LABT
      TPT=0.007
      TR=X/D*1/2*B
      BB=0.022
  102 CONTINUE
      TBR=TR*LABT
      BBR=BB*LABB
      IF(TBR.GT.BRR)  LABT=LABT-1
      IF(TBB.GT.BRR)  LABB=LABB+1
      IF(TBR.GT.BRR)  GO TO 102
      PRINT 66,LABT,LABB
   66 FORMAT(10X,'LABOR TRANSPORT IS',2X,I4,2X,'LABOR BUNDLNG IS',2X,
     9I4,//)
      LABTOT=LABTOT+LAB
```

```
DAY =   39    NO RAIN THRESH

                    AREA TO THRESH=        0.1400
                    AREA THRESHED=        0.8000

DAY =   40    NO RAIN THRESH

THRESHING COMPLETE

7.00    0.0       0.9400    0.0       0.0       0.9400    0.0       0.9400

                    TOTAL PRE HARVEST LOSSES(KG)=      15.08
                    TOTAL POSTHARVEST LOSSES(KG)=      21.48
                    TOTAL BIRD AND RODENT LOSSES(KG)=      41.10
                    TOTAL BUNDLING LOSSES(KG)=      22.71
                    TOTAL TRANSPORTATION LOSSES(KG)=      54.12
                    TOTAL GRAIN LOSSES(KG)=     155.48

                    TOTAL LABOR USED=            59
************************ ************************************************************************ **********************

TIME     HA TO     HA        HA TO     HA TO     HA        HA TO     HA
         HAVST     HAVSTD    BNDL      TRNSPT    TRSPTD    THRSH     THRSD
*** ***********************************************************

                    % BROKEN GRAIN =        33.48

       NO LABOR FOR HARVEST

                    % BROKEN GRAIN =        34.47

DAY =   37  LABOR =     7          NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=    19.63
                    SUN CHECKS%=     89.59
                    PRE HARVEST LOSSES(KG/HA)=      20.45
                    TOTAL LOSS PRE HARVEST(KG)=      37.82
                    BIRD & RODENT LOSSES(KG/HA)=      56.43
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      53.04
                    TOTAL BIRD & RODENT LOSSES(KG)=     103.70

HARVEST INCOMPLETE

8.05    0.0947    0.8452    0.8452    0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=      28.42
```

```
                SUN CHECKS%=    92.75
                PRE HARVEST LOSSES(KG/HA)=      21.12
                TOTAL LOSS PRE HARVEST(KG)=      39.82
                BIRD & RODENT LOSSES(KG/HA)=      58.97
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      5.59
                TOTAL BIRD & RODENT LOSSES(KG)=     109.29

      LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     4

 DAY =   39    RAIN TRANSPORT DH

                GRAIN MOISTURE%=   18.65
                SUN CHECKS%=    95.91
                PRE HARVEST LOSSES(KG/HA)=      21.79
                TOTAL LOSS PRE HARVEST(KG)=      41.88
                BIRD & RODENT LOSSES(KG/HA)=      61.51
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      5.83
                TOTAL BIRD & RODENT LOSSES(KG)=     115.11

      LABOR TRANSPRT IS     4  LABOR BUNDLNG IS     3

  BUND AND TRANS OF DH COMPLETE

4.95     0.0947     0.8452     0.0      0.0      0.8480     0.0      0.0

                BUNDLING LOSS (KG/HA)=     30.67
                TOTAL BUNDLING LOSSES(KG)=      25.08
                TRANSPORT LOSS (KG/HA)=     70.94
                TOTAL TRANSPORT LOSSES(KG)=      59.06

                % BROKEN GRAIN =       38.16

 DAY =   40  LABOR =     8          NO RAIN, LABOR    AVAILABLE, HARVEST

                GRAIN MOISTURE%=   19.13
                SUN CHECKS%=    99.07
                PRE HARVEST LOSSES(KG/HA)=      22.46
                TOTAL LOSS PRE HARVEST(KG)=      44.01
                BIRD & RODENT LOSSES(KG/HA)=      64.33
                BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      6.07
                TOTAL BIRD & RODENT LOSSES(KG)=     121.18

 HARVEST COMPLETED

0.80     0.0      0.9400     0.0960     0.0      0.8480     0.0      0.0

                POST HARVEST LOSSES(KG/HA)=      31.79
                TOTAL LOSS POST HARVEST(KG)=      27.07

 DAY  =   41    BUNDLING AND TRANSPORT
```

```
                 TOTAL BIRD AND RODENT LOSSES(KG)=     121.18

 HARVST HADLNG AND TRNSPT COMPLTE

2.25    0.0      0.9400    0.0      0.0      0.9400    0.8480    0.0

                 BUNDLING LOSS (KG/HA)=      32.92
                 TOTAL BUNDLING LOSSES(KG)=      28.19
                 TRANSPORT LOSS (KG/HA)=      75.76
                 TOTAL TRANSPORT LOSSES(KG)=      66.42

                 AREA TO THRESH=        0.9400
                 AREA THRESHED=        0.0

 DAY =   42    NO RAIN THRESH

                 AREA TO THRESH=        0.7800
                 AREA THRESHED=        0.1600

 DAY =   43    NO RAIN THRESH

                 AREA TO THRESH=        0.6200
                 AREA THRESHED=        0.3200

 DAY =   44    NO RAIN THRESH

                 AREA TO THRESH=        0.4600
                 AREA THRESHED=        0.4800

 DAY =   45    NO RAIN THRESH

                 AREA TO THRESH=        0.3000
                 AREA THRESHED=        0.6400

 DAY =   46    NO RAIN THRESH

                 AREA TO THRESH=        0.1400
                 AREA THRESHED=        0.8000

 DAY =   47    NO RAIN THRESH

 THRESHING COMPLETE

7.00    0.0      0.9400    0.0      0.0      0.9400    0.0      0.9400
```

```
                    TOTAL GRAIN LOSSES(KG)=     286.88

                    TOTAL LABOR USED=            71
********************** ******************************************************************* **********************

TIME     HA TO      HA       HA TO      HA TO      HA       HA TO      HA
        HAVST     HAVSTD      BNDL      TRNSPT    TRSPTD    THRSH     THRSD
*** ***********************************************************

                    % BROKEN GRAIN =       38.16

 DAY =   40  LABOR =     7         NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   18.13
                    SUN CHECKS%=    99.37
                    PRE HARVEST LOSSES(KG/HA)=     22.46
                    TOTAL LOSS PRE HARVEST(KG)=     21.11
                    BIRD & RODENT LOSSES(KG/HA)=     64.05
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      60.21
                    TOTAL BIRD & RODENT LOSSES(KG)=     60.21

 HARVEST INCOMPLETE

8.05     0.0947     0.8452     0.8452     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=     31.79
                    TOTAL LOSS POST HARVEST(KG)=     26.87

 DAY =   41  LABOR =     6         NO RAIN, LABOR    AVAILABLE, HARVEST

                    GRAIN MOISTURE%=   17.57
                    SUN CHECKS%=   102.23
                    PRE HARVEST LOSSES(KG/HA)=     23.13
                    TOTAL LOSS PRE HARVEST(KG)=     23.30
                    BIRD & RODENT LOSSES(KG/HA)=     66.59
                    BIRD & RODENT LOSSES FOR TOTAL AREA(KG)=      6.31
                    TOTAL BIRD & RODENT LOSSES(KG)=     66.52

 HARVEST COMPLETED

1.10     0.0        0.9400     0.9442     0.0       0.0       0.0       0.0

                    POST HARVEST LOSSES(KG/HA)=     32.92
                    TOTAL LOSS POST HARVEST(KG)=     30.13

 DAY  =   42    BUNDLING AND TRANSPORT

      LABOR TRANSPORT IS     6  LABOR BUNDLNG IS     4
```