Arundo donax: Source of Musical Reeds and Industrial Cellulose

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Arundo donax—Source of Musical Reeds and Industrial Cellulose

***Arundo donax** has played an important role in the culture of the western world through its influence on the development of music. Reeds for woodwind musical instruments are still made from the culms, and no satisfactory substitutes have been developed. This grass has also been used as a source of cellulose for rayon and considered as a source of paper pulp.*

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Introduction

The grass family is well known as a source of many important economic plants. The cereal grains form the most important source of food for mankind and grains and forage types provide the complete diet of many domestic animals. Sugar cane is the principal source of sugar. Bamboos are widely utilized in tropical and subtropical areas and many species of grasses are employed as lawn plants. Several grasses, notably esparto, are used for the manufacture of paper, species of *Cymbopogon* and *Vetiveria* provide essential oils, and the seed heads of broom corn provide raw materials for the manufacture of brooms.

From the viewpoint of the quantity utilized or its monetary value, *Arundo donax* L. is a grass of relatively minor importance, but this plant has played an important role in the culture of the western world through its influence on the development of music. The plant has a long history, perhaps as long as that of any other species with the exception of the basic food plants. Its utilization in the creation of music can be traced back 5,000 years.

The plant was well known to ancient peoples of the Middle East. The term "reed" is of frequent occurrence in the Bible, and at least some of these references allude to *Arundo donax*. Biblical writers provide little information as to the utility of the plant but by simile made use of its well-known characteristics, its tenacity, rigidity, vigor and the nature of its surroundings in expressing their ideas or in creating imaginative descriptions of phenomena of their day.

Today, reeds for woodwind musical instruments are still made from *Arundo donax* culms, the same material that has been employed throughout the history of these instruments. This is a rather unusual case in which modern technology has been unable to develop a satisfactory substitute although, during times of shortages, much effort has been expended in this direction and, from time to time, musicians have turned in desperation to a variety of other materials.

A considerable quantity of the grass has been used as a source of cellulose for rayon manufacture, and the plant has received consideration as a source of paper pulp.

Botany

The genus *Arundo* of the family Gramineae, tribe Festuceae, includes about six species of which *A. donax* L. is the most widely distributed and the best

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known. *A. conspicua* Forst., a native of New Zealand, is widely grown in European gardens as an ornamental. *A. pliniana* Turra is native to the countries bordering the Mediterranean Sea and is utilized to a limited extent for forage. *A. formosana* Hack. is native to Formosa; *A. fulvida* J. Buch. and *A. richardi* Endl. are native to New Zealand.

Common Names. Because of its widespread distribution and extensive utilization by man, *Arundo donax* has assumed many common names. In the southwestern United States, the plant is sometimes called by the Mexican name *carrizo.* In English-speaking countries in general, it is called bamboo reed, Danubian reed, donax cane, giant reed, Italian reed, Spanish reed, or Provence cane, as well as by such general appellations as cane, reed, or bamboo.

In other countries, the most widely employed names are merely translations of the simple epithets "cane" or "common cane". The most important names, some of which are applied also to *Phragmites communis,* are as follows: Burma: alokyu; Egypt: kasab; France and French Africa: canne, canne de Provence, roseaux; Germany: Pfahlrohr, Pfeilrohr, Riesenschilf; Greece: kalamos; India: bara nal, gaba nal, narkul; Italy: calami, caneviera, canna, canna berganega, canna di cannitu, canna commune, canna domestica, canna montana, canna da rocchi, canna di stenniri, ciane gergane, donaci, gutamu, virtamu; Spain and Spanish speaking countries: cana comun, canna de Castilla.

In Italy, the form with variegated leaves is known as *canna zagariddara.*

With several exceptions in which the meaning will be clear from context, the term "reed" is employed in this paper only in reference to the sounding mechanism of a musical instrument.

Description. *Arundo donax* is a tall, erect, perennial, cane-like or reed-like grass, 2 to 8 m. high. It is one of the largest of the herbaceous grasses. The fleshy, almost bulbous, creeping rootstocks form compact masses from which arise tough fibrous roots that penetrate deeply into the soil. The culms reach a diameter of 1 to 4 cm. and commonly branch during the second year of growth. They are hollow, with walls 2–7 mm. thick, and divided by partitions at the nodes. The nodes vary in length from approximately 12 to 30 cm. The outer tissue of the stem is of a siliceous nature, very hard and brittle with a smooth glossy surface that turns pale golden yellow when the culm is fully mature. The leaves are conspicuously two-ranked, 5 to 8 cm. broad at the base, tapering to a fine point. The leaf sheaths are tightly wrapped around the stem and often persist long after the blades have fallen. The flowers are borne in large, terminal, plume-like panicles 30 to 60 cm. long.

Morphologically, *Arundo donax* is comparatively uniform. A variegated variety of the species, known only in cultivation, was described in Miller's Gardener's Dictionary in 1768. This form is now known as *A. donax* var. *versicolor* (Mill.) Kunth, and in most respects is a diminutive of typical *A. donax.* In its most familiar form, this variety has culms up to 1.5 cm. in diameter that reach a maximum height of 4 to 5 m. but are frequently but .6 to 1 m. high. This plant produces a more dense growth than does typical *A. donax* due to a greater production of culms as well as to a greater production of leaves and is less hardy than the latter. By selection of off-shoots other variegated forms have been propagated that do not differ significantly from typical *A. donax* except for their variegated leaves.

Cane grows very rapidly. Growth at a rate of .3 to .7 m. per week over a period of several months is not unusual when conditions are favorable. Young culms develop at approximately the full diameter of mature cane, but their walls increase in thickness after the initial growing season. The new growth is soft and very high in moisture and has little wind resistance.

Distribution. *Arundo donax* is native to the countries surrounding the Mediterranean Sea. From this area, it has become widely dispersed, mostly through intentional introduction by man, into all of the subtropical and warm-temperate areas of the world. In many areas it has become well established. The plant is abundant in India, ascending to elevations of 8,000 feet in the Himalayas, and has been dispersed eastward to Burma and China. The species appears to be absent from central Africa but has been successfully introduced into the southern part of that continent. It has been introduced into Australia and many islands of the Pacific and Atlantic oceans.

Donax cane has also been widely dispersed in the New World, from the southern United States southward through Central and South America. It occurs in most of the islands of the West Indies, as well as in Bermuda and the Bahamas. In the United States, the plant has been cultivated successfully as far north as Washington, D. C., and escapes from cultivation as far north as Virginia and Missouri. It has been widely planted, often as an ornamental, throughout the warmer states, especially in the southwestern part of the country where it is used along ditches for the prevention of erosion. There are abundant wild growths along the Rio Grande River.

The cultivation of cane for woodwind reeds has been largely limited to a very small area in southeastern France in the adjoining Departments of Var and

FIG. 1. A cultivated cane brake (*Arundo donax*) in California. (Photo courtesy of Arnold Brilhart)

FIG. 2. A small ornamental planting of *Arundo donax* in California. This species is commonly used as an ornamental in the warmer sections of the United States. (U.S.D.A. Photo)

Alpes Maritimes. Cane has also been cultivated for this purpose to a small extent in Texas and California. Cultivation of the plant for use as a source of industrial cellulose has been largely limited to northern Italy. Donax cane is widely cultivated, on a small scale for local use, in Italy and other countries around the Mediterranean Sea.

Ecology. *Arundo donax* tolerates a wide variety of ecological conditions (10, 14, 27, 28, 35, 42). It is reported to flourish in all types of soils from heavy clays to loose sands and gravelly soils. It tolerates excessive salinity and will survive extended periods of severe drought accompanied by low atmospheric-humidity or periods of excessive moisture.

The plant produces the most vigorous growth in well-drained soils where abundant moisture is available; its favored environment is along the border of lakes or along ditches and canals. Along the Rio Grande the most abundant growths occur on fertile soils well above the river bed that become flooded only during rare flash floods. Very little cane grows at lower levels (14).

The plant's ability to tolerate or grow well under conditions of apparent extreme drought is due to the development of coarse drought-resistant rhizomes and deeply penetrating roots that reach deep-seated sources of moisture. Cane can be seriously retarded by lack of moisture during its first year, but drought does not cause grave damage to patches 2 to 3 years old. From the standpoint of moisture requirement cane produces satisfactory growth in areas that are suitable for the cultivation of corn (28).

Arundo donax is a warm-temperate or subtropical species. When dormant, it is able to survive very low temperatures but is subject to serious damage by frosts that occur after the initiation of spring growth. The plant does not flourish under true tropical conditions.

In nature, cane is able to flourish on soils that are apparently very infertile. Under cultivation the plant is responsive to improved soil fertility and is particularly favored by abundant nitrogen. In soils of low fertility, especially those lacking in nitrogen, the buds of the rhizome are produced at a greater distance apart than in fertile soils and there is much greater expansion of the underground structures. In Argentina, annual cane yields in infertile, partly fertile and fertile soils were 4, 6, and 8 tons, respectively, of dry cane per acre (28).

This species does not produce viable seed in most areas to which it is apparently well adapted. However, plants have been grown from seed collected in Afghanistan, Baluchistan, and Iran.

Anatomy. *Arundo donax* stems exhibit typical monocotyledonous structures (16, 27, 40). Although the vascular bundles are distributed freely throughout the cross-sectional area of fundamental parenchyma, those toward the periphery of the stem are smaller and more numerous than are those toward the interior. The vascular bundles are collateral and are surrounded by one or more rows of thick-walled, strongly lignified fibers. These fibers are long and narrow and taper to a fine point. The larger bundles of the interior are commonly enclosed by a single row of fibers. Toward the periphery of the stem, as the size of the bundles decreases, the number of rows of fibers associated with the bundles increases. Near the exterior of the stem, where the bundles are small and comparatively close together, the fibers are sufficiently abundant to form a continuous ring of structural tissue within which are scattered the vascular elements. This structural ring is separated from the epidermal layer by a narrow band of parenchyma cells that in mature stems are comparatively small, thick-walled, and lignified.

The vascular bundles, with the exception of those near the periphery of the stem, are embedded in thin-walled parenchyma the innermost cells of which are very large with inter-cellular spaces at their angles.

The vascular bundles, including the associated fibers interior to the structural fibrous ring, occupy approximately 24% of the total cross-sectional area of the stem. The vascular tissue and associated fibers that compose the structural ring make up approximately 33% of the total cross-sectional area. Thus, parenchymatous tissue occupies but 43% of the cross-sectional area of the stem.

The single layer of epidermal cells is covered with a waxy cuticle. In the tangential plane, the walls of most of these cells form a strongly sinuous outline. Scattered through the epidermis are short-roundish or irregularly shaped cells and typical gramineous stomata.

Both leaves and stems of *Arundo donax*, particularly the former, contain numerous highly silicified cells. These cells are associated with the vascular bundles and are also located in the epidermal tissue. Their presence explains the relatively high silica content that has been indicated by chemical analyses.

Utilization: Reeds for Musical Instruments

Fundamentally, woodwind instruments consist of a tubular or conical resonator within which sound waves are generated by the vibrations of a reed, as for the clarinet or oboe, or by the passage of a stream of air against the edge of a small aperture in the tube, the manner of sounding the flute. The tone generated by a woodwind is a function of the length of the resonator and is controlled by opening one or more of a series of apertures.

Reeds for modern musical instruments are of three types. The single beating-reed, employed with clarinet and saxophone, consists of a tongue or strip of cane, thinned gradually at one end to a broad delicate tip. The base of the reed is clamped to a mouthpiece with the thin vibrating blade overlapping an opening which leads into the resonator. When at rest, the reed is positioned in such a manner that there is a slight space between the blade and the mouthpiece. When played, the reed vibrates or beats against the mouthpiece. The double beating-reed, employed with the bassoon and oboe, consists of two pieces of cane arranged back to back. When played, the thin blades of the two elements vibrate against each other. Reeds of both types are used in modern bagpipes although the single reed for this instrument differs somewhat from that described above. The free-reed used in the mouth organ, reed organ, and concertina consists of a thin metal element which vibrates freely through an arc and does not beat against any part of the instrument. *Arundo donax* has apparently not been used at any stage in the

Fig. 3. A well-developed rhizome system of *Arundo donax*. (U.S.D.A. Photo)

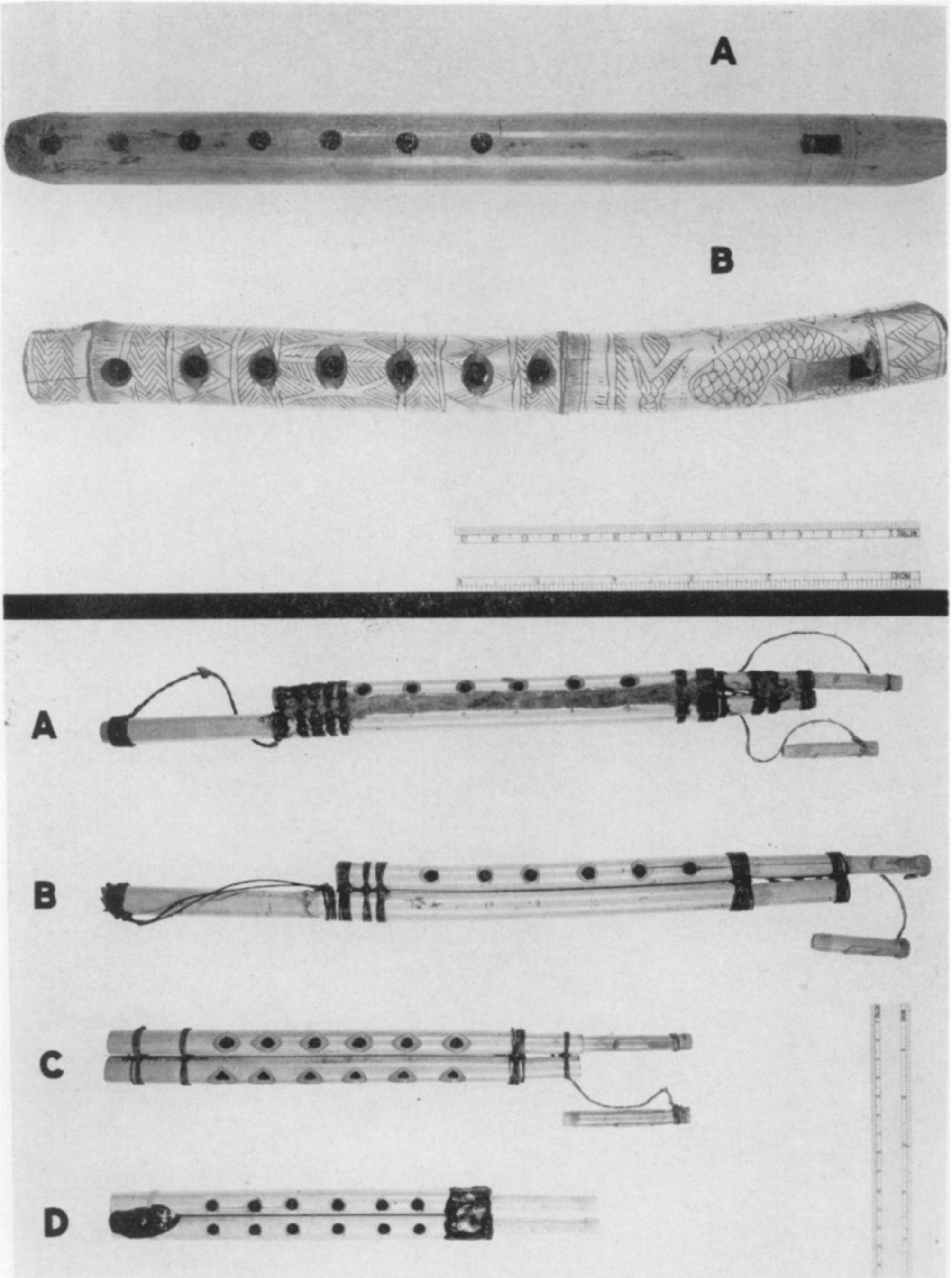

FIG. 4 (Above). Modern whistle- or fipple-flutes formed from *Arundo donax* cane. Each pipe is closed at the lower end by a node. The upper end is fitted with a plug in which a sound hole has been cut. A thumb hole is located on the reverse side of each pipe opposite the upper-

development of the free reed and consequently this type is not further discussed in the present paper.

History

In the music world today, *Arundo donax* is most familiar as the source of raw material for the manufacture of reeds for woodwind instruments. The origin of donax cane as a material associated with musical instruments is surprisingly linked, not with an ancestor of one of the above instruments, but with a primitive ancestor of the flute (5, 7). That a hollow tube could be made to produce a characteristic sound and that hollow tubes of varying lengths could be made to produce different sounds could hardly have gone long unrecognized by primitive man. Thus, the opportunity for the discovery of the primitive woodwind has long been before man, whether as a hollow bone or as a tube of bamboo or donax cane.

It would be difficult to estimate the earliest date at which canes of *Arundo donax* were first used for making flutes. Relics of the early Stone Age show that man knew how to form a single-toned pipe from bone. The earliest type, the nay, or vertical form, was closed at the base and sounded by blowing across the open end of the tube. Later, pipes were sounded by blowing across an aperture placed just below the closed upper end of the tube and were held in a horizontal position. By the late Stone Age the bone flute had been improved by the addition of one or more finger holes resulting in an instrument that could sound several notes. Early man soon discovered that a much more satisfactory instrument could be fashioned from a tube of vegetable material. Around the Mediterranean basin canes of *Arundo donax* were the classical raw material for this purpose, and their use originated independently of the use of bamboo for the same purpose in the Orient and islands of the south Pacific and the use of other materials in North and South America. Primitive flutes or flute-like instruments appear to have been developed by most primitive peoples.

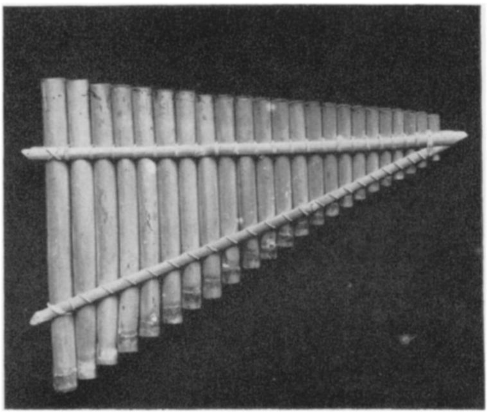

FIG. 6. Modern Egyptian Pan pipe constructed of *Arundo donax* cane. Each tube is closed at the base by a node and lashed to the cane cross-pieces and adjacent tubes with cord. The instrument is played by blowing across the open ends of the tubes. (Photo courtesy of Smithsonian Institution)

From the most simple vertical flute, it

most finger hole. A. Moroccan flute. B. Egyptian flute, ornamented with incised designs filled with black pigment. (U.S.D.A. Photo, instruments from Smithsonian Institution collection)

FIG. 5 (Opp., below). Modern eastern-Mediterranean double-pipe single-reed instruments, reeds and resonators formed from *Arundo donax* cane. These instruments do not differ appreciably from pipes employed several thousand years ago in Egypt and Mesopotamia. Each reed is formed from a hollow piece of cane, stopped at one end by a node. A horizontal slit is cut into the tube, penetrating into the cavity, to form the vibrating tongue or reed. A. Syrian urgun. The pipes are cemented together with wax and lashed with waxed cord. The unperforated drone-pipe, below, sounds but a single note. B. Egyptian arghool. The pipes are lashed with waxed cord. C. Syrian naigha. Each of the melody pipes is fitted above with an extension. D. Iraqi cane instrument. The two melody pipes are cemented together with bitumen. (U.S.D.A. Photo, instruments from Smithsonian Institution collection) was but a simple step to the development of the Pan pipe or syrinx. This primitive instrument consisted of from several to as many as 25 pipes, varying in length from three to approximately ten inches, each sounding a different note. The tubes were arranged so that their open ends were in a horizontal row and were attached, each to its neighbor or to one or two cross pieces, by a crude twine or adhesive. The Pan pipe was typically constructed from culms of *Arundo donax*, the stopped ends of the tubes formed by joints of the cane. Pan pipes have persisted as folk instruments in the present culture of southeastern Europe and are still made of donax cane.

The Pan pipe is believed to have formed the basis for the origin of the most primitive pipe organ. The earliest organ of record, dated at approximately 200 B.C., is comparatively complex and a far cry from the Pan pipe, but was referred to by Greek writers of the time as a syrinx or as a syrinx played by hand. The primitive organ provided a mechanism for creating a wind supply and included a wind chest, to which flue pipes of donax cane were attached. Additional mechanisms were provided to permit the passage of air through the pipe, or pipes, of the musician's choice. The appropriate note for each pipe was created by the vibrations resulting from the passage of air against the edge of a slit cut into each cane tube. As the evolution of the organ progressed, the craftsman abandoned *Arundo donax* cane for tubes of wood or metal.

While the earliest stages of the development of the flute can be found in relics, early pictorial records, and among instruments in use by primitive peoples of the world's present population, early stages in the evolution of instruments sounded by a reed are not very well known (5, 7, 20, 33). The mechanism of the double reed may have been discovered when primitive man compressed the end of a pliable hollow stem between his teeth and created a non-musical flutter with the pressure of his breath. Or possibly, the principle of the double reed was recognized when man first forced his breath between two blades of grass. The most primitive type of single-reed mechanism was a squeaker of hollowed cane or other plant material with a long rectangular section raised from its surface to create a vibrating tongue. The first reed of this type was thus continuous with the resonator. A vibrator so attached to the "mouth piece" is referred to as an idioglottal reed. Whether the double or the single reed is the primitive type is not known, but it appears likely that the double reed came first or that both were developed at about the same time. As we know it today, the double reed is far more complex in structure and manufacture, but it is actually less complex in its origin and evolution.

The first significant development following the origin of the simple squeaker was the use of a longer tube perforated with one or more finger holes to vary the tone. When the fragile reed became damaged or worn, it was necessary that the entire instrument be discarded. As the craftsman began to devote increased attention to the perfection of the resonator, the need for a reed attached to a separate mouthpiece became evident; an arrangement that would provide for replacement of the reed but permanent use of the improved resonator was necessary. This second important improvement closely followed the adoption of the longer perforated tube.

A majority of primitive peoples of the present day are ignorant of reed instruments. Although the reed mechanism, as a simple squeaker, may have been developed independently by different primitive peoples, the initial stages apparently did not give rise to further development except in Egypt and southwestern Asia. Advanced instruments of this type have been discovered in the hands of primitive peoples in various parts of the world, but in most instances it is possible to attribute the invention to the early peoples of the middle East.

The factors primarily responsible for this origin are the unique characteristics of *Arundo donax* which make it the finest raw material for formation of the reed mechanism and the original geographic distribution of the plant around the Mediterranean Sea and along the Nile. Thus, of the early civilizations, only those of Egypt and Arabia had available the one material that could be most effectively developed. Throughout the entire period that reed instruments were under the influence of north African or southwestern Asiatic peoples, donax cane provided the preferred raw material for the reed and the most easily adapted and most favored material for the resonator as well. The structure of the cane, apparently unique among plant materials, has provided a substance with ideal characteristics of resilience, elasticity, and resistance to moisture. It forms a superb vibrator that responds instantly to minute changes in pressure and does not crack or split under the adverse conditions of intermittent but frequent contact with moisture.

Archeological evidence indicates that the reed woodwind, as a musical instrument rather than as a simple squeaker, originated in Egypt or in Mesopotamia. At the earliest point in history at which we have evidence of the existence of these instruments, their use was already well established in the life of these peoples. Our knowledge of these early woodwinds is based upon discoveries from Egyptian tombs and ruins of early Sumerian cities in southeastern Iraq. The oldest representations have been found in the painting and sculpture of the Egyptians, the most ancient literary references in the cuneiform writings of the Sumerians.

The first Egyptian reed-woodwind on record was a single tube of cane with finger holes. Pipes of this type are known to have been in use before 3,000 B.C. and by this time, both single and double reeds had probably been developed. Double pipes consisting of parallel cane tubes held together by wax or bound with string were also in use. Each pipe was equipped with a vibrator, both of which were placed in the mouth to sound the instrument. These tubes were each perforated with finger holes, but probably sounded the same or nearly the same notes. Representations of Egyptian double-pipe instruments have been identified on sculpture dated about 3,000 B.C.

In Mesopotamia, the double-pipe instrument was modified to form a V-shaped double pipe, probably played with two single reeds. This is the most familiar type in early paintings and sculpture. Ebony, bronze and silver, as well as cane, were used for the resonator. An idioglottal reed was cut into a detachable mouthpiece or in the case of some cane instruments cut into the end of the resonator. Some of the double pipes had an equal number of finger holes in each tube. Others had only one tube with perforations, the unperforated tube sounding a single tone unless furnished with extensions. About 1600 B.C., the V-shaped double pipe was carried back into Egypt and from this period on is represented in profusion on Egyptian sculpture, almost to the exclusion of other types.

These primitive instruments, changed but little from the early Egyptian pipes from which they descended, are still in use in Egypt and throughout the Moslem world.

The Moslems were largely responsible for the dispersal of the reed woodwind. They spread the pipe into China,

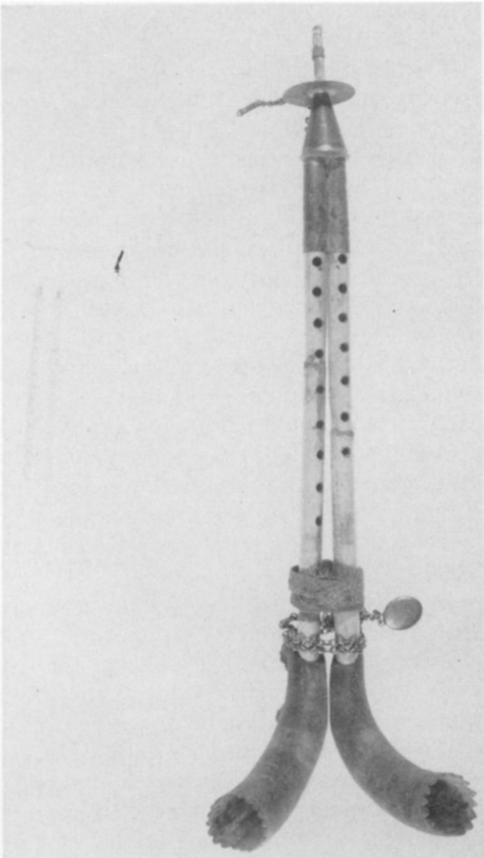

FIG. 7. Modern Moroccan reed instrument constructed of *Arundo donax* cane, tin plate, and cow's horn. The single reed is an idioglottal primitive-type like those shown in Fig. 5. (U.S.D.A. Photo, instrument from Smithsonian Institution collection)

the East Indies, Europe and North Africa, and indirectly, through the early Spaniards, to the Americas.

The Egyptian-Arabian pipe spread to Crete and then to Greece when Crete was invaded by the Greeks about 1,100 B.C. The earlier Greek pipes were mostly double-reeded. The single-reed type was not used until about 300–400 B.C., although the Greeks were apparently long aware of the single-reed mechanism.

The first important changes in the musical pipe since its initial development by the Egyptians and Arabians 3,000 or more years previously were brought about by the Greeks. The mouthpiece, previously employed with the hinge of the idioglottal reed toward the player, and engulfed completely in the mouth, was altered so that the hinge of the reed was away from the lips. The instrument was played with the lips pressed against the reed. As the position of the lips changed, the length of the vibrating tongue could be varied, altering the fundamental pitch of the pipe. In addition, the Greeks varied the length of the mouthpiece and gradually increased the number of finger holes to as many as 16 in some pipes. As the number of finger holes increased, a system for closing chosen holes of the resonator was devised by use of metal bands held in place by rings encircling the tube. The bands were perforated and arranged so that various finger holes could be partially or completely covered or left open.

With the overthrow of the Greeks during the middle of the second century B.C. by the Romans, the musical pipe was carried to Rome. Little change resulted although the resonator came to be made of bone, wood, or metal as well as of cane. With the decline of Roman culture, during the fifth century A.D., the reed pipe as then known and its science disappeared.

During the Dark Ages, all musical instruments were frowned upon by the Church and the use of the highly developed reed woodwind died out in Europe. As modified by the Greeks and used by the Romans, this pipe was a very intricate instrument, not a simple folk instrument like the early form developed by the Egyptians and Arabians. Performance on the pipe was a real art and thus required the attention of a true artist. It was far too complicated for survival during this period in the hands of the peasant. This highly developed instrument was thus an end line of evolution, completely submerged by the darkness of the Medieval Age, an extremity of a branch of the family tree whose main trunk was to culminate in the modern reed-woodwind.

For the origin of our modern reed instruments we must return to the primitive pipe developed by the Egyptians and Arabians. Of the many folk instruments of the reed-woodwind type that date from medieval times, some of which are in use today, most can be traced to an origin in southwestern Asia. A Sardinian instrument made from three cane tubes has evolved from a primitive instrument brought to Sardinia by the Phoenicians about 500–700 years B.C. Reed instruments were also brought to Europe by the Moors who overran Spain and part of France between 700 and 800 A.D. and who held on in Spain for an additional 700 years. A folk instrument of cane used in the Balearic Isles may be a relic of this invasion. Knowledge of the reed woodwind possibly reached the British Isles as a result of communication between Moorish Spain and Wales. It is possible, however, that the primitive British and Balearic types developed as a result of earlier Celtic migrations. Migration to the west eventually spread the knowledge of the reed instrument throughout a large part of Europe.

From this widely distributed, simple, primitive woodwind, our modern clarinets, oboes, bassoons, etc., have evolved. During the years following the dawn of the Renaissance other musical instruments became widely established, but the woodwinds were hardly known. The tones produced by these instruments were oriental in nature, sensitive, piercing, whining tones that appealed to eastern rather than western ears. In addition, these instruments had associated with them certain acoustical problems which were not to be solved until many years later.

Up until this time, the woodwind had been most consistently made of cane. The reeds were typically idioglottal though frequently cut into cane mouthpieces and used with resonators of other materials. As the use of these instruments spread farther north into Europe, farther from the native home of *Arundo donax*, it became necessary to employ other raw materials. For the resonator, boxwood and other European woods came into use. The use of such nonvibrant raw materials was followed by the development of the heteroglottal reed (not continuous with the mouthpiece, but attached to it by string, hide, or other material). Many materials were used for the vibrating tongue but over the centuries, none proved so satisfactory as donax cane.

During the 17th to 19th centuries, the single-reed-type instrument was improved and developed into a family of many instruments including the true 18th century clarinet and 19th century saxophone; the double-reed type, evolved into the oboe, English horn, and bassoon and their relatives.

The layman generally does not recognize the bag pipe as a reed instrument, although this woodwind employs both single and double reeds prepared from stems of donax cane. The bag of this instrument serves as a flexible wind chamber from which the expulsion of air is controlled by pressure of the musician's arm. Air is supplied by a bellows carried under the opposite arm or by blowing into a tube connected to the bag. One to four reeds are completely enclosed within a comparable number of tubes which are attached to one end to the bag. One pipe, the chanter or melody pipe, encloses a typical double reed and is equipped with holes or keys to vary the tone. The remaining pipes, the drones, enclose idioglottal single reeds, and, lacking a mechanism for varying the tone, sound but a single note. Control is not exercised over the pipes independently; all operate in unison.

The single reed of the bag pipe is of special interest, for even in the most modern pipes, this reed does not differ from that employed in the most primitive single-reed instruments developed some 5,000 years ago. A single reed for this instrument is prepared from a slender tube of cane, closed at one end by a joint, by cutting transversely into the hollow of the cane to a depth of about 2 mm. and then raising a tongue in the side of the tube by cutting longitudinally for a distance of about 5 cm.

The most primitive bagpipe on record was employed by the Romans during the reign of Nero, but the principles of the instrument were known at a much earlier date. During at least a part of the early history of the instrument, donax cane was used for reeds. As the use of the instrument passed to the north, far removed from the native home of *Arundo donax*, other materials were employed. The use of cane was renewed at an undetermined date when supplies of this material were made available by improved transportation.

Today, one can only speculate as to what would be the nature or quality of our music, both classic and modern, had not *Arundo donax* been available to the early civilizations of Egypt and southwestern Asia and the later civilization of Europe. Undoubtedly, the initiative of the early artisan would have culminated in the successful application of another material to the making of reeds. Can we comprehend the effect of such a material upon the evolution of music?

Growth Requirements

Most musicians and reed makers hold the opinion that the environmental requirements for production of quality cane are highly rigid and that there is something highly specific about the soils and atmosphere of southern France that is responsible for the production of good cane. Beyond this there is little agreement as to the most satisfactory conditions. The opinion held by some is that the cane should be grown in clay soils while others firmly believe that only loose sandy soils will produce the finest quality material. It is generally agreed that low atmospheric humidity is desirable.

The fact that good-quality reeds have been made from cane obtained from Spain, Italy, Sicily, North Africa, Kenya, South America, Mexico, Cuba, Texas, California, and Virginia suggests that soil and other conditions are not as rigid as they are generally considered to be.

Arundo donax is well adapted to a wide variety of soil conditions. With all factors taken into consideration, it appears that the most suitable habitat for the production of raw material for reeds is a deep light soil, which provides adequate moisture for maintenance of continued growth but does not contain sufficient moisture for a highly vigorous development that would result in the formation of soft porous cane. A site near the sea is regarded as preferable to a more inland location.

Cane Production in France

The production of cane for the manufacture of reeds is restricted to the coastal area of southeastern France in the Departments of Var and Alpes Maritimes, within the district formerly known as Provence. The most important plantations are in the vicinity of the coastal town of Fréjus.

Cultivation. New plantings are started by vegetative propagation. Planting material is obtained by digging and dividing old rootstocks or occasionally by rooting cuttings. Large canes may be cut in June and placed horizontally in shaded, moist, sandy soil. Young plants develop at the nodes and after reaching a satisfactory size are separated and removed to the fields. The rhizomes or rooted cuttings are placed in rows 2 to 3 m. apart and covered with soil to a depth of about 10 cm. The plants are watered if necessary during the first year and are hoed once or twice. Until the ground becomes covered with cane, the space between the rows may be utilized for the cultivation of potatoes, beets, and other similar crop plants.

During the early development of a planting, the canes are cut periodically to encourage spreading of the rhizomes and to increase the density of the stand. Established plantings receive little attention other than the periodic removal of large weeds and the small or most inferior canes. Some growers remove leaves before harvest to allow exposure of the canes to the sun and use the foliage for animal feed or bedding.

Harvest. The new plantation requires up to five years growth before producing the first full crop of good-quality cane. In established plantations, canes to be used for reeds are selectively cut during the winter months, when they are two or three years old. During harvest, any cane that is too old for use in reed manufacture is removed to allow better growing conditions for the following year's crop.

FIG. 8. Sun-curing cane in Var Province, France. (Photo courtesy of Luther P. Hines)

Drying and Curing. Treatment of the harvested cane varies greatly and largely depends upon the opinion of the individual grower or upon the preference of the reed manufacturer for whom the cane is destined. The newly harvested canes are tied in large bundles, often with leaves and branches intact. These bundles are stacked erect with the cane bases spread out in such a manner as to form a pyramid; they may be gathered into shocks around a post, or the bundles may be stacked erect against either side rot and often stain the outside of the cane, producing a mottled appearance. This does not affect the quality of the cane. In fact, mottling is regarded by some musicians as an indication of high quality. The initial drying stage re-

FIG. 9. Curing Mexican-grown cane in Arizona. The tubes are arranged on string to facilitate handling. (Photo courtesy of J. W. Manson)

of a horizontal timber supported at a height of 2 to 3 m. above the ground.

Certain growers prefer to initiate seasoning of the cane under a tree or open shed or provide protection from the sun by covering the south side of the bundles with grass or cloth.

Cane is not harmed by rain. During the initial drying period, the leaf sheaths

quires at least two to four months during which the moisture within the cane drains out or is otherwise dissipated. Following this period the upper branching portions of the canes are removed, the remaining leaves and sheaths are cleaned away and the canes are cut into lengths of about four feet. Any spoiled or cracked canes are discarded.

The quality stocks are next cured in the sun. The selected canes are suspended horizontally on low supports or laid obliquely along a fence, rope, or other support stretched between poles at a height of about three feet above the ground. Some growers arrange the supports so that they are oriented in a north-south direction. This is to prevent cracking of the cane and the development of an undesirable red coloration which may result from excessive exposure to the sun. As soon as the surface exposed to the sun turns to a creamy color, the canes are turned so that another surface is exposed to the sun's rays.

The cane is turned once or twice as the grower prefers. Exposing the cane in three operations is generally preferred as it results in a more uniform color. This period of curing takes at least three weeks, and a longer period is often considered more desirable.

The total period of outdoor drying varies greatly. The cane may be dried for six to twelve months, and some advocate an even longer period. In certain instances, sun drying is supplemented by kiln drying.

Following sun curing the cane is stored in sheds. It may be retained in storage for a further indefinite period of curing or immediately marketed. By the time the cane is used by the reed maker it may be as much as three to five years old. The total period of seasoning, as well as the growing period, is influenced considerably by the demands of the market.

By the time properly-seasoned cane is ready for use, it has turned to a rich golden-yellow. The cane is sectioned into tubes by cutting about 1 cm. on either side of the nodes. Tubes of poor quality are eliminated. These include tubes with walls too thin or too thick, tubes of unsuitable diameter, those that are cracked or not straight, and those that are of poor color or otherwise of inferior appearance. Tubes, in 50-pound lots, are packed in bags and shipped to manufacturers or distributors.

Yield. Estimates of the average annual yield of dry matter from *Arundo donax* vary from 3.2 tons per acre for wild stands in India (32) to 17.5 tons per acre for plantings cultivated in Italy for the production of viscose rayon (24). The latter figure can be accepted as a maximum, and some idea of the yield of cane suitable for reeds can be derived from it. Of the dry matter produced, over 50% consists of leaves and the upper branching portion of the cane that cannot be utilized for manufacture of reeds. This leaves a total production of less than 10 tons per acre from which raw material for reeds can be selected. Not more than 10% of this quantity can be used. Only a small proportion of the yield has the proper diameter, and of this, much of the cane has walls either too thick or too thin. Many canes are discarded because they are crooked, cracked, or otherwise imperfect, and a large portion of the stock is discarded when the nodes are removed.

Cane Production in Other Areas

The Department of Var in southern France is the traditional center of the production of cane to be used for reeds. Var cane was widely recognized as the only quality material, and this monopoly of the French growers was not contested prior to World War I. As a result of the war, cane shortages in other parts of the world became acute and the shortage persisted for several years. It was reported that during the war years, Senegalese troops billeted among the French cane fields, consumed enormous quantities of cane for fuel and construction of shelters, and were responsible in part for the later shortages of cane and its poor quality. As a result of the wartime and post-war shortages, musicians in the United States made limited efforts to establish domestic sources of cane. Small plantings were established in California, Texas, Georgia, and Alabama; some were from rhizomes introduced from the cane plantations of southern France, and others from rhizomes of unknown origin. None of the cane from these plantings was reported to be satisfactory. Sporadic efforts were made during the decade preceding World War II to grow suitable cane in this country but without success. With the then adequate supplies available from France, the main stimulus for developing an American source slackened.

During the early stages of World War II the cane supply again became short, and renewed efforts were made to develop sources within the United States. Cane from existing plantings, mostly ornamentals or escapes, was collected and tested by musicians, reed manufacturers, and concerns previously engaged in importing cane or finished reeds. Shortly, satisfactory cane was discovered along the Rio Grande in southern Texas. As a result of this discovery several strains including materials introduced from Iran and Afghanistan by the U. S. Department of Agriculture were planted for comparison at Brownsville, Texas. Details of later progress are lacking, but the cane produced on 10 acres was reported to have been harvested in sufficient time to be made available to manufacturers by early 1942. Whether this cane was acceptable to the manufacturer is not known, but several musicians employed it successfully. This cane at $1.25 to $4.00 a pound was advertised in trade publications at the time, the price varying according to the type of instrument for which it was selected. This cane-growing operation was not successful and was later discontinued.

During this same period, considerable effort was devoted to the establishment of cane production in California with most of the same strains planted in Texas. Good-quality cane was made available to musicians, several of whom have reported that fine-quality reeds could be made from it. Cane production in California decreased considerably after World War II, as French cane again became available, but as late as 1950 one producer was advertising California cane grown from imported French stock. At present cane is being cultivated for reed manufacture by at least one grower.

The search for a new supply of cane by American musicians also resulted in the discovery of suitable quality materials in Sonora, Mexico. These naturalized growths were exploited to a considerable extent during and just after World War II. Cane was collected by one manufacturer in the vicinity of Guaymas and transported to Arizona for curing. Another concern set up a factory near Nogales to carry out the preliminary processing of local cane, and the reeds were finished in New York City. Mexican cane is currently sold in the United States, one dealer recommending it for student reed-making practice. This cane is now used to a very limited extent by reed manufacturers.

The World War II shortage of cane resulted in the successful establishment of plantations by the Russians in the Caucasian area (22). This cane is reported to have been very unreliable at first but, with improvements in methods of cultivation and seasoning, it is now a very satisfactory raw material.

Reed Making

Prior to the middle of the nineteenth century the making of all types of cane reeds was a craft practiced by specialists working alone or by the musician who made his own. With the development of suitable machinery, the making of single reeds has been gradually converted to a mass-production basis. As double reeds are highly intricate and must be tailored closely to the specific requirements of the individual instrument and musician, their manufacture has largely remained in the hands of the individual reed maker or musician. A few manufacturers produce double reeds, principally for student use.

FIG. 10. The worker in the background is sorting cane tubes according to diameter requirements of the various instruments. The worker in the foreground is splitting the cane by driving the tubes onto a cane-splitter. (Photo courtesy of French American Reeds Mfg. Co., Inc.)

Cane received by the reed maker is in the form of short tubes, varying in diameter and wall thickness, cut from between the nodes of donax culms. The tubes are sorted into sizes appropriate to the instrument for which reeds are to be made. Among the single-reed instruments, the E- or B-flat clarinets and soprano saxophone require the smaller sizes; the bass clarinet and bass saxophone require the larger. Among the double-reed instruments, small-size canes are used for oboe reeds and larger ones for bassoon reeds.

Single reeds are made from cane tubes 7 to 10 cm. long and 2 to 3 cm. in diameter (36, 43). The tubes are separated into quarter sections with a cane splitter, a tool consisting of four sharp metal blades, set perpendicular to one another near the tip of a vertical shaft, in appearance somewhat like the feathers that guide an arrow. Tubes of cane are placed on the shaft and driven down over the blades with a wooden mallet. The quarter sections are carefully cut into appropriate lengths with a saw.

The medullar surface of the quarter section is flattened with a plane, and the cane is trimmed along the edges to the exact width of the finished reed. The quarter section is then planed on the flat surface to its final dimension. The blade is shaped by cutting away about half of the rounded epidermal surface, tapering it at one end, to an edge as thin wide. The tip of the blade is approximately .075 to .175 mm. in thickness, and the base of the blade is 3.20 to 3.65 mm. in thickness.

The finished reeds are spot-tested on an instrument, but none of the reeds to be sold can be so examined. Prior to packaging, the reeds are graded as to strength in five or more grades from very

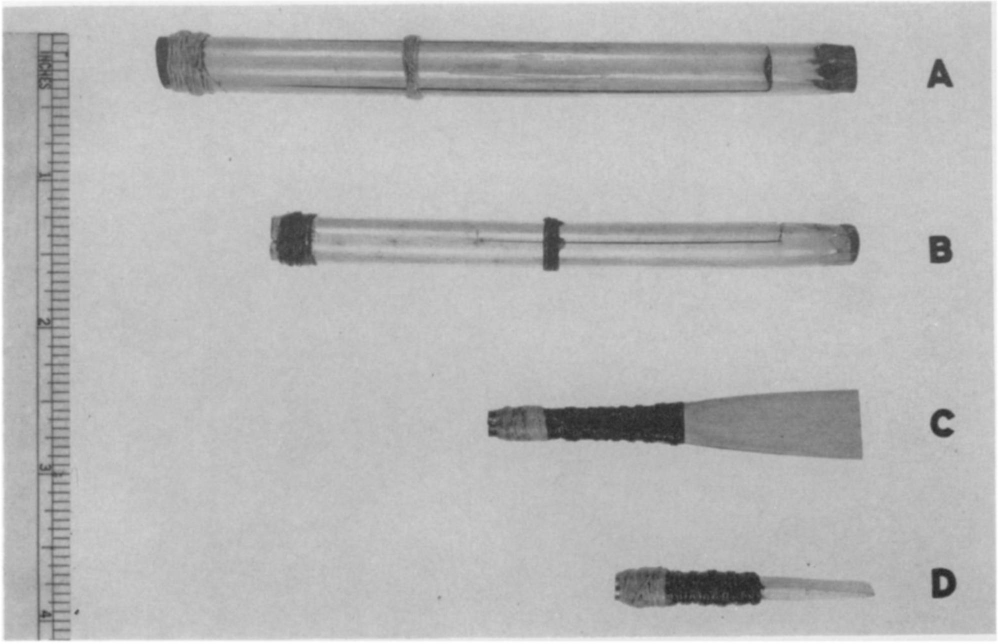

FIG. 11. Bag pipe reeds formed from *Arundo donax* cane. A and B. Base and tenor drone reeds. These single reeds do not differ appreciably from those employed with ancient Egyptian and Mesopotamian reed instruments. The cord wrapping at the base serves for tight insertion in the instrument. The upper cord wrapping can be moved up or down to adjust the tone of the reed. The reeds are stopped at the upper end by a node, the pores of which are sealed with beeswax. C and D. Double reeds for practice chanter and chanter. (U.S.D.A. Photo, reeds courtesy of William C. Stokoe, Jr.)

as paper. The portion removed is cut away by a plane passing over a jig in which the cane is set with a pattern. The surface of the blade is finished with sand paper; the paper-thin tip of the blade is filed square and then rounded off with a guillotine-like trimmer.

As an example of the dimensions of a finished single reed, a small size for clarinet is about 6.5 cm. long and 1.1 cm. soft to very stiff. This quality is more an indication of the shape and thickness of the blade and is not greatly affected by the nature of the cane from which the reeds were made.

Double-reed manufacture is considerably more complex than the manufacture of single reeds (3, 13). In contrast to the single reed, the flat surface of which is clamped tightly to the flat outline of a mouthpiece, the medullar surface of the double reed must be transversely curved so that it can be closely attached to the staple or bocal by which it is joined to the instrument. The staple is a slender brass tube, the basal end of which is placed in cork for firm insertion in the instrument. While the single reed consists of a short section of cane, tapered at one end to a thin edge, the double reed consists of a long piece of cane, scored and then folded at the midpoint with epidermal surfaces exposed, and tapered to a thin dimension at the midpoint.

Oboe reeds are manufactured from cane tubes about 15 cm. long and 1 cm. in diameter. The tubes are split into three sections, and these are trimmed along the edges to a uniform width and sawed off at a uniform length. The sections are placed in a machine, and the inner surface is gouged to such a degree that the cane is about .6 mm. thick at the thickest point and tapers uniformly to the edges. In order to close the grain left open by gouging and to smooth the surface, the cane is scraped with a circular blade arranged somewhat like that of the familiar glass cutter.

During the subsequent steps the cane is repeatedly soaked in water to simplify cutting and bending. The cane section is placed on an easel (a rounded, dowel-like support) and transversely scored at the midpoint of the epidermal surface with a sharp knife, just cutting through the hard outer tissue. It is placed over the edge of a knife blade and folded double along the line of the shallow cut. The wet cane is then placed in a shaper. This tool consists of a blade that is broad at the end and tapers somewhat toward the base, where a clamp is set on each of the two surfaces to hold the ends of the cane in place. With the cane folded over the shaper blade and clamped in place, the edges are trimmed to conform to the outline of the blade. The shaped cane is straightened and placed on the easel, and the two ends are beveled on the epidermal edge with a file. The cane, still wet, is folded again and the edges are smoothed with fine sand paper.

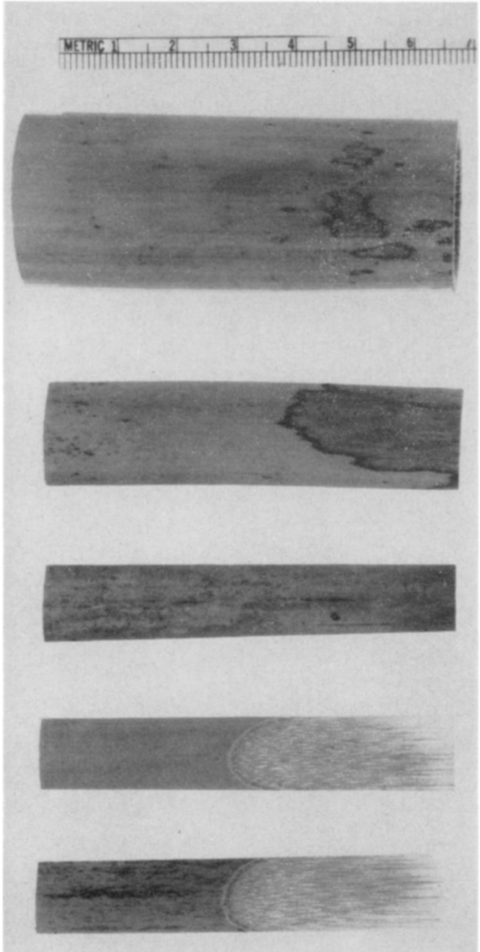

FIG. 12. Stages in the preparation of clarinet reeds. From top to bottom: cane tube; cane quarter section; reed blank, flattened on medular surface; blank with shaped blade; completed reed with rounded tip. (U.S.D.A. Photo, cane courtesy of Arnold Brilhart)

A tubular staple is inserted between the free ends of the folded cane to a distance of about ¼ inch, and the ends are firmly clamped in place with fine wire in such a manner that the edges of the reed come together completely. At a point just beyond the end of the staple the reed is wound tightly with fine silk thread. The wire is then removed and the winding completed down to the cork.

After the cane is dry the face or lay of the reed is prepared. By drawing the end of the double reed over a file, first one edge and then the other, the two edges are beveled to form a gently inclined face of triangular shape. The two terminal edges are filed until only a few unsevered fibers hold the two reed elements together. The tip of the reed is placed upon a block, and a minute portion is cut off square, separating the two cane elements. With a thin oval plaque inserted between the tips of the two elements, the lay is scraped until the corner of the triangle most distant from the tip has been rounded. The tip is then scraped very thin, and minute adjustments are made to adapt the reed to the requirements of the individual musician and his instrument.

The base of the reed is wrapped with a small wet sheet of filmy material that shrinks when dry. When dry, this wrapping and the silk winding are covered with a special reed cement.

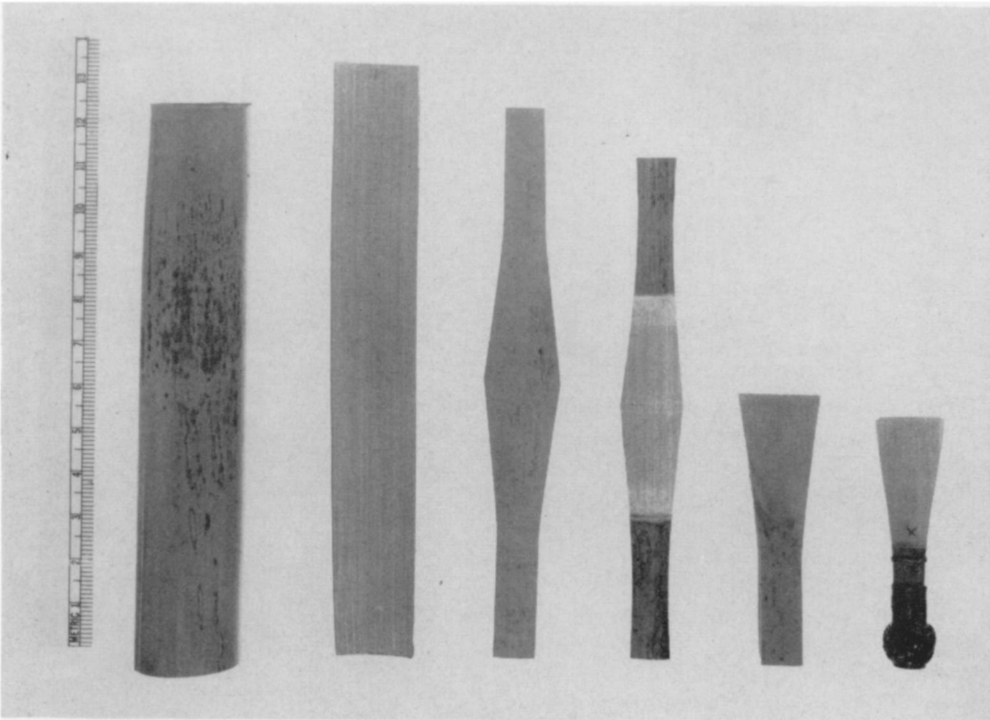

FIG. 13. Stages in the preparation of bassoon reeds. From left to right: cane tube, trimmed and gouged cane section, gouged surface showing; shaped gouged-cane; shaped gouged-cane with blade partly cut; folded cane with blade partly cut; completed reed. (U.S.D.A. Photo, cane courtesy of Jack Spratt)

Preparation of reeds for the English horn does not differ significantly from preparation of reeds for the oboe but requires larger cane and certain larger or otherwise different tools.

Double reeds for the bassoon are prepared from cane tubes about 2.8 cm. in diameter. They are split, trimmed, and gouged to a size 2 cm. wide, 12 to 14 cm. long and 1.25 mm. thick at the center, tapering to about .5 mm. along the edges. The gouged cane-section is clamped in a shaper and trimmed to conform to the outline of the shaper. The shaped cane is approximately 1.8 cm. wide at the midpoint and 1 cm. wide at each end. The epidermal surface is scored crosswise with a knife at points 2.5 cm. on each side of the mid-point. With a knife and finally a file, the cane is tapered down from each score to the mid-point until the latter is about .25 mm. thick. The edges of the cane that will form the basal part of the finished reed and that will finally surround the tubular staple or bocal are beveled with a file to an angle of about 45°. With the cane laid on a block, the remaining epidermal surfaces are scored lengthwise with a knife along the two portions that will form the basal part of the finished reed. These scores are cut very lightly, just through the hard surface, about 1 mm. apart. The cane is folded at the mid-point and the two ends are doubled together with scored epidermal surfaces on the outside and bound together firmly with several pieces of fine wire. The base of the reed splits evenly along the scores as it is forced on a mandrel, a tapering tubular tool attached to a long handle, used to hold the reed during the final stages of preparation.

The two faces of the reed are tapered down to the tip with a file. The reed is then placed on a block and the tip cut away squarely, separating the two cane elements. A flat plaque is inserted between the tips of the reed, and the faces are scraped with a knife until they vibrate freely when played. The tip and edges just above the tip of the finished reed are very thin, and the middle and the upper surfaces are slightly rounded. At this stage the reed is wrapped and finished more or less in the same manner as described for oboe reeds. The completed reed is removed from the mandrel and attached to the bocal of the instrument.

Production and Prices

Official statistics are not available on the quantity of cane produced or the number of reeds manufactured in either the United States or France. Production of cane in France for the manufacture of reeds is roughly estimated at 200,000 to 300,000 pounds per year, of which 40,000 to 50,000 pounds is shipped to the United States. French manufacturers produce 15,000,000 to 20,000,000 reeds annually and market about one-third of these in North America. Approximately 20,000 pounds of cane are produced in the United States, and American manufacturers produce from 5,000,000 to 7,000,000 reeds each year. The total quantity of reeds sold in the United States amounts to between 10,000,000 to 15,000,000 annually. Probably 95% of these are single reeds for clarinet and saxophone.

American grown cane in large lots is priced at about 40 cents per pound. French and Spanish cane in large lots is valued at $1.10 to $1.95 per pound for top quality and $.85 to $1.25 for unselected cane of assorted thickness. On a retail basis, tubes of selected French cane sell for $5.00 to $8.50 per pound. Mexican cane is currently quoted at $2.00 per pound.

Single reeds for clarinet and saxophone sell for 20 to 60 cents apiece; single reeds for bagpipe drones are about 25 cents each. Finished oboe reeds are valued at $1.30 to $1.75, and finished bassoon reeds at $1.50 to $3.50. Double reeds for bagpipe chanter cost 50 to 75 cents.

Quality of Cane and Reeds

Prior to World War II, when the cane shortage was extremely acute and musicians were forced to turn to any available source, it was generally accepted that high-quality cane could be obtained only from a special strain of *Arundo donax* and that only the environment of southern France could produce good cane. Today there is no doubt but that each of these precepts is a fallacy; however, a great majority of musicians still insist that French cane is far superior to any other. As pointed out previously in this paper, cane from many geographic sources has been successfully used for the production of reeds. Several writers have reported that Spanish, Mexican, and American canes when distributed as "French" have been judged to be of finest quality by outstanding musicians. When the same lots of cane were correctly labeled as to origin, they were considered to be very inferior.

Musicians and manufacturers are fairly well agreed that it is difficult to distinguish good from bad cane by visual examination unless there are obvious flaws. Although the characteristics of quality cane are intangible, many criteria have come to be widely accepted.

Cane of a rich golden yellow color with a shiny surface is preferred; cane of a greenish tinge was either too young when cut or was not properly cured and is likely to be too soft. Cane with a flat, dull, dirty color is also unsatisfactory. Such discoloration apparently results from unfavorable conditions during the early stages of curing or from a fungus disease of the plant. The grain must be fine, straight and regular with tiny but prominent, even, parallel ribs. Material suitable for making reeds is considered to be more dense than ordinary cane. Cane that is soft with loose fibers or overly porous is unsatisfactory.

In the finished reed, the veins should extend to the tip. The reed should produce a good tone and vibrate correctly at all pitches of the instrument. For quick response, it must be flexible and highly resilient.

A favorite test is to wet a reed or piece of cane and blow hard through one end. If bubbles develop at the opposite end the material is regarded as being too porous.

One correspondent has found, in a quest for a material suitable for use in scientific instruments, that French cane used in woodwind reeds has a density of .4 while American cane has a density of .5. From criteria established by musicians just the opposite would be expected.

The application of scientific methods to the testing of cane quality has been very limited. The usefulness of data gained by such an approach is limited to some degree by the varying preferences of individual musicians. One study of hardness, stiffness, and elasticity of cane indicates that the most satisfactory reeds are made from soft canes that show the least stiffness and the greatest amount of recovery after bending. The degree of recovery after bending was considered to be one of the most important characteristics associated with tone quality and response of the finished reed (31).

Possibility of Cane Production in the United States

The experience of American musicians during World War II with cane of American origin establishes without question that good-quality cane can be grown in this country. Much must be learned, however, before a consistently good product can be marketed, and it is questionable whether such an American product can compete cost-wise with French cane under present conditions. As pointed out earlier in this paper, even in France only a small proportion of the yield is considered satisfactory for making reeds. A significant portion of the French growers' income is obtained from the sale of lower grade supplies for use in making baskets, fish poles, and other products. The United States does not have outlets to absorb cane that is below reed grade, but such a market might be developed.

The only possibility that can be foreseen for intensive cultivation of *Arundo donax* in the United States is as a source of industrial cellulose. Under present conditions, this possibility must be considered as remote. Should cane be cultivated for this purpose, economic factors probably would restrict its growth to the more humid areas where the highest yields could be obtained. It is doubtful that cane produced in such areas would be suitable for reeds.

Any American cane made available at a price and quality competitive with the French product will still have a great psychological disadvantage. A majority of musicians are thoroughly convinced that only cane from France is suitable for their use. This belief can be attributed to the many dismal failures of non-French cane as well as to the good reputation that French cane has long enjoyed.

A careful study of atmospheric and soil conditions under which cane is produced in southeastern France should point the way to the selection of the most satisfactory American environment. Such an environment appears most likely to be found in the southwestern or western United States. Careful study of the botanical and agronomic characteristics of the plant, in connection with detailed study of the physical and musical quality of cane, would provide a firm basis on which attempts to establish the industry could be made. It is questionable whether the industry could profitably support the expense of the necessary research.

Cane Substitutes

In times of acute shortages musicians have attempted to form reeds from a wide variety of materials including boxwood, ebony, heather root, lancewood, teakwood, celluloid, hard rubber, synthetic resins, ivory, and silver. All of these materials proved unsatisfactory.

During World War II, a musician made reeds from bamboos, *Phyllostachys bambusoides* and *Semiarundinaria fastuosa*. These materials were much too hard and entirely undesirable.

Elder stems and goose quills were formerly employed very extensively to make drone reeds for bagpipes. The requirements of these reeds are less rigid than those of other types.

During World War II, the U. S. Department of Agriculture experimented with several substances in an effort to develop a tasteless water-proofing material for cane reeds. It was found that ethyl cellulose, a tasteless chemical, could be used for this purpose. Reports were received that treated reeds were very satisfactory, but this method has not been accepted by the most critical musicians.

During recent years much experience has been gained in the manufacture of plastic reeds and they are currently in wide use in high school and college bands. Plastic reeds have not gained the acceptance of professional musicians who complain of poor tone and the slippery nature of these reeds resulting from their lack of porosity. If these problems can be overcome, plastic may in time completely replace cane, for manufacture of reeds from plastic can be much more easily controlled. Plastic reeds are now available for clarinet, saxophone, and bassoon.

Utilization: Industrial Cellulose

The high production of vegetative material by *Arundo donax* has long attracted the attention of those interested in the production of paper. As early as 1830 samples of paper were made from

TABLE 1

FIBER DIMENSIONS OF *Arundo Donax* CULMS (MM.)

Source	Length	Average Length	Width	Average Width
Imperial Institute (2)	0.25–4.57	1.52		
Raitt (32)	0.62–2.25	1.50	0.012–0.037	0.017
Onofry (27)	0.6 –5.4		0.020–0.025	
Jayme *et al.* (17)	0.1 –5.0			
Bhat & Virmani (8)	0.80–2.80	1.45		

this plant by boiling stem material that had received a prolonged treatment in calcium hydroxide. Increased interest in this plant has been expressed periodically during the present century in nations where supplies of pulpwood have become critically low, especially during the years just before and during World War II.

Fiber Dimensions. In fiber length (Table 1), an important index of potential pulp or paper strength, *Arundo* compares favorably with deciduous tree species, the average fiber length of which ranges from approximately 1 to 1.8 mm. It compares less favorably with coniferous species, in most of which the average fiber length is 3.5 to 6.0 mm. The length : diameter ratio of *Arundo* fibers is approximately 75 : 1, compared with a ratio of approximately 100 : 1 for fibers from both deciduous and coniferous trees. Other factors being equal, pulp with a high fiber length : diameter ratio produces stronger, more finely textured papers. In a comparative study of crop residues and native German plants, which included 25 species of non-woody or semi-woody plants, Jayme *et al.* (17) reported that *Arundo donax* fibers are of greater length than those of any other species examined except hemp.

Onofry (27) separated a stem into five sections and measured fiber lengths in each separately. In each sample, approximately 70% of the fibers measured fell within the range of 1.2 to 2.0 mm.

A test of cane sulfate-pulp on a screen classifier indicated that about 50% of the fiber is retained on a 28-mesh screen and 35% on a 100-mesh screen, and that 15% passes through the latter (14).

Chemical Composition. A summary of chemical analyses of *Arundo donax* culms is given in Table 2. While it is difficult to compare data of this type because of the varying methods of analysis, these figures collectively give a good

TABLE 2

CHEMICAL COMPOSITION OF *Arundo Donax* CULMS *

Source	Cellulose %	Pentosans %	Lignin %	Ash %	Alcohol-benzene solubility %
Raitt (32)	42.8	33.6†	9.4	7.4	
Tomeo *et al.* (39)	40.1– 44.4	22.7– 27.5	23.4– 24.4	3.8– 4.8	10.7– 11.9
Jayme *et al.* (17)		24.3	16.4	2.9	
Bhat & Virmani (8)	58.0	18.4	22.0	3.6	6.8
Kocevar & Javornik-Kosler (18)	43.8 (alpha)	20.8	22.4	2.5	

* All figures on oven dry basis.
† Includes pectose, fat, and wax.

indication of the chemical nature of the plant.

The higher cellulose analysis (58%) cited from Bhat and Virmani (8) can be attributed to their use of the Cross and Bevan method for this determination. Cross and Bevan cellulose contains a considerable proportion of hemicellulose and is here reflected in the lower content of pentosans. On the basis of Cross and Bevan cellulose content, *Arundo donax* compares favorably with wood (50–60%)[2] and bamboo (57–66%) and is somewhat better than most of the grain straws (45–52%). In the previously mentioned study by Jayme *et al.* (17), bleached *Arundo donax* pulp had a higher alpha cellulose content (89.3%) than any other pulp tested.

Arundo donax contains considerably less lignin than woods (25–30%), somewhat more than grain straws (12–19%), and in this respect compares favorably with most bamboos (14–32%). Lignin is the principal constituent that must be removed to produce a fine pulp, and, as a rule, plants with low lignin content can be expected to pulp easily.

In pentosan content donax cane does not differ greatly from bamboo (15–21%), grain straws (25–30%), or hardwoods (20–25%) but contains considerably more than soft woods (8–14%). Like the other grasses donax cane has a high ash content (grain straws 5–10%, bamboo 1–3%), considerably higher than wood (usually under 1%). The silica content of the culm ranges from 1 to 2%.

Experimental Digestion for Pulps. Table 3 presents selected experimental data summarizing the currently available research on the soda, sulfate, and bisulfite digestion processes for the production of paper pulp from *Arundo donax*. The digestions represented in the table were in most cases selected from two or more parallel treatments as illustrating the most suitable procedures for producing the highest yields of pulps that possessed satisfactory strength qualities and that could be bleached to a satisfactory degree of whiteness with an economical amount of bleaching powder. Crushing of the material and chipping it into small fragments before processing speed up penetration of the cooking liquor into the stems (8). Penetration is hampered by the low permeability of the outer layers of the stem due to their high density and the presence of a considerable amount of wax.

The leaves make up as much as 45% of the total dry weight of the raw material but contribute little to the pulp produced (8). Leaves digested under conditions similar to those indicated for digestions 3 and 4 yielded only 29% unbleached pulp and required slightly more alkali than was required for digestion of culms or mixtures of culms and leaves. Bleaching of the leaf pulp required twice as much chemical as was required for bleaching of the culm pulp. This refinement caused a 50% reduction in weight of the leaf pulp in contrast to a 14% reduction in weight of the culm pulp.

Di Felippo (11) reported that laboratory tests with leaves produced a bleached pulp yield of only 26.1%. The breaking length of this sample (the length of a strip of paper required to cause the strip to break under its own weight) was 2,800 m. Under comparable conditions, cane accompanied by sheaths and leaves gave a bleached pulp yield of 34.0 to 35.5% with a breaking length of 6,250 to 7,000 m. Canes without leaves or sheaths yielded 40.7 to 45% bleached pulps with breaking lengths of 6,300 to 6,800 m. Leaves produce pulp of poor strength but do not effect strength properties appreciably when pulped with culms. In addition to producing lower yields of pulp and re-

[2] Percentages cited for wood, bamboo, and grain straws are approximate.

ducing, capacity-wise, the efficiency of the digester, leaves increase the amount of material soluble in alkali which increases the consumption of chemical and contributes to the formation of pulps with a jelly-like consistency. Washing of such pulps is difficult. The combination of leaves with stems also leads to lack of uniformity in the degree of cooking unless expensive, more drastic treatments are used.

Item 8 in Table 3 provides the essential details of a pilot-plant scale digestion of *Arundo donax* with an equal quantity of *Phragmites karka*. The latter is an Indian grass, similar in appearance and habitat to *Arundo donax*, and frequently confused with it in the field (9). The digestion produced a clean well-cooked pulp in an amount comparable to yields obtained when *Arundo donax* was cooked alone. This pulp was formed into a sheet on a machine operated at a speed of 50 feet per minute, producing a writing paper with satisfactory strength properties. Tests of this paper (machine direction) indicated a breaking length of 2680 m. and a tear factor of 41.1. The burst factor was 17.1. Since the pulp from these two grasses is short fibered, addition of a quantity of long-fibered pulp

TABLE 3

EXPERIMENTAL DIGESTION OF *Arundo Donax* FOR PAPER PULP

Source	Process	Total chemical (as Na_2O) (%)	Time (hours)	Temperature (°C.)	Yield unbleached pulp (%)	Remarks
1. Raitt (32)	Soda	16.3	6	153	37.0	Starches previously extracted.
2. Dupont & Escourrou (12)	Soda	21.1	3	160	42.5	Raw material contained 8.1% moisture.
3. Bhat & Virmani (8)	Sulfate	13.2	6	153–162	42.6	Without leaves. Yielded 36.3% bleached pulp.
4. Bhat & Virmani (8)	Sulfate	13.2	6	153–162	35.0	With leaves. Yielded 30% bleached pulp.
5. Bhat & Virmani (8)	Soda	14.0	6	153–162	45.0	Without leaves. Yielded 38.3% bleached pulp.
6. Bhat & Virmani (8)	Soda	14.0	6	153–162	35.0	With leaves. Yielded 27.1% bleached pulp.
7. Tomeo, Herrero, & Astor (37)	Sulfate	17.5	5	170	42.0	
8. Bhat & Virmani (9)	Sulfate	17.1	6	153–162	43.3	Mixed with equal quantity of *Phragmites karka*. Yielded 34.5% bleached pulp.
9. Dupont & Escourrou (12)	Bisulfite SO_2 (Free SO_2) Na_2O	(gm./l.) 65.6 (56) 9.3	12	123	45.3	Raw material contained 8.6% moisture, extracted with H_2O, 1 hr. at 100° C.

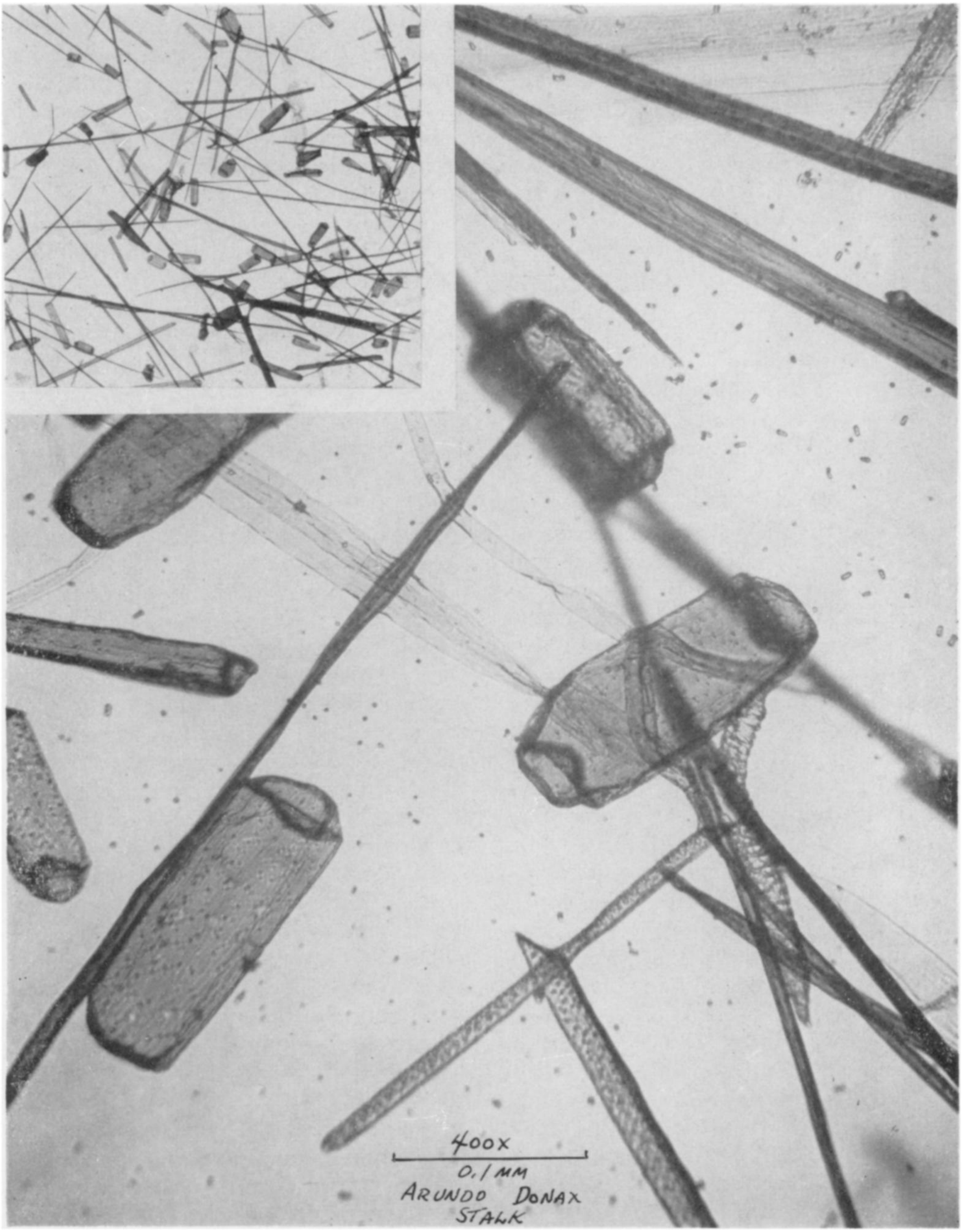

FIG. 14. Macerated *Arundo donax* culm, sample from internode, 400×. (Insert 50×). (U.S.D.A. Photo, courtesy of Northern Utilization Research and Development Division, Agricultural Research Service).

would be necessary before it could be used on a high speed commercial machine.

Large-scale tests have been made in the United States by Gaylord Container Corporation on 1000 tons of cane obtained from wild stands along the Rio Grande (14). Cane cooked by the sulfate process with 7.5 to 13.5% active alkali for 2.5 to 3 hours gave pulp yields of 35.6 to 52.4%. The pulps were very weak. In comparison with a refined pulp from pine having a bursting strength of 61.4, tear strength of 93, and tensile strength of 19, pulps from *Arundo donax* that were refined to the same freeness had bursting strengths of 32 and 37, tear strengths of 57 and 48, and tensile strengths of 12 and 16. A satisfactory corrugating sheet was produced, but it was not comparable in strength with the sheets regularly produced by the mill. Mixtures of cane and pine pulps showed a decrease in strength more or less in direct proportion to the quantity of cane pulp used.

In the mill-scale tests just discussed, mixtures of cane and Kraft pulps were used to produce papers of several types. All were of poor strength and had smoother formation and higher dirt count than Kraft papers and were slower draining on the wire. The papers from the mixed pulps were easier drying. It was concluded that cane is not satisfactory if strength is important, but it may serve for the production of special papers.

A number of mill-operating problems were evident during processing of the cane. The large quantity of dust created by shattering of the cane resulted in unpleasant working conditions. Digesters did not blow clean, and washing of the pulp was difficult. Among other unfavorable factors, the high silica content of the cane caused serious scaling of equipment and created difficulties in liquor recovery.

The entire culm of *Arudo donax* breaks up comparatively easily, unlike culms of many bamboos and other grasses in which the nodes resist disintegration. The pulps are easily and economically bleached. In comparison with pulp from coniferous wood, they are of but medium strength because of their comparatively short fibers. However, they are satisfactory for the production of writing and printing papers, and their strength can be increased considerably by the addition of 10% of long-fibered coniferous pulp. Strength properties of standard sheets formed of bleached pulps obtained in digestions 3, 4, 5, and 6 of Table 3 were: breaking length 9,348 m., 9,650 m., 9,325 m., 9,017 m.; tear factor 116, 113, 114, 90; burst factor 57, 53, 54, 54. Raitt (32), taking into consideration all aspects of the utilization of grasses for paper pulp, considered donax cane to be one of the outstanding Indian grasses that might be used for this purpose. This grass could be pulped separately or in mixture with any of six other outstanding Indian species. Like pulps from other non-woody plants, *Arundo donax* pulps have a content of foreign matter that is considerably higher than wood pulp.

Pulps with high alpha-cellulose content are desirable for the production of special papers including those where permanency is a major requirement. They are also used as dissolving pulps for the manufacture of rayons, cellophane, cellulose-acetate, cellulose-nitrate, and other cellulose derivatives. A great portion of high-alpha pulp is utilized in the production of rayon. A pulp to be used for this purpose must have an alpha cellulose content greater than 92%, a pentosan content less than 2.5%, an ash content less than 0.11% and must be lignin-free. The pulp must also have suitable physical characteristics. For the production of cellulose acetate and other cellulose derivatives, the chemical requirements are more rigid than for pulps to be used for rayon.

Acid hydrolysis of raw cane, prior to digestion, favors the production of pulps with a high alpha-cellulose content (12, 18, 37, 38). The content of pentosans is reduced, and there is a parallel reduction in the pentosan content of the final pulp. The most complete data on the acid hydrolysis of *Arundo donax* culms are those given by Kocevar and Javornik-Kosler (18) for experimental treatments of material described in Table 2. Prehydrolysis of this culm material with .5% and 1.0% H_2SO_4 at 135° C. for 3 hours yielded extracted culms in quantities of 77% and 65%, respectively, with pentosan contents of 8.6% and 7.0%. These two extracted samples, when digested by the sulfate process ($NaOH$, Na_2S, Na_2CO_3) with 3% total alkali (as Na) for 5.5 hours at a maximum temperature of 170° C., furnished crude pulps in yields of 34% and 29%. The two crude pulps analysed as follows: alpha cellulose 87.0%, 90.6%; lignin 4.6%, 3.1%; pentosans 6.4% 4.8%; ash .44%, .29%. When refined by bleaching, alkali extraction and a second bleaching, the pulps contained: alpha cellulose 95.0%, 96.3%; pentosans 3.6%, 2.9%; ash .13%, .11%. The refined pulps were lignin-free and were produced in yields equivalent to 25% and 22% of the weight of the original material.

In contrast to the two trials cited above, less drastic acid hydrolysis of raw culms with .1% H_2SO_4 for six hours at 135° C. decreased pentosans only slightly, from 20.8% to 20.4%. With digestion and refinement conditions parallel to those cited, this trial yielded 29% of refined lignin-free pulp with 88.5% alpha cellulose, 6.6% pentosans, and .14% ash. Closely comparable results were obtained by Tomeo *et al.* (37, 38) employing 1% H_2SO_4 at 120° C. for 30 minutes.

Experimental hydrolysis of raw cane with nitric acid is reported by Dupont and Escourrou (12). Their data include so many variables that generalizations are difficult. A sample previously extracted with boiling water to give a 10% dry extract, when treated with 3.7% HNO_3 at 100° C. for 2 hours yielded 18.5% of dry extract containing 14% reducing sugar. Digestion of the extracted material with 9% NaOH at 100° C. for 1 hour yielded 43.4% of crude pulp. Hydrolysis of a sample with 2.4% HNO_3 at 100° C. for 3 hours yielded 49% dry extract containing 27% reducing sugars. Digestion of this extracted residue with 12.9% NaOH at 115° C. for 2 hours yielded 41.4% of crude pulp. The crude pulp contained 81% alpha cellulose. By bleaching, the alpha cellulose content was increased to 85.2%. Fermentable sugars can be recovered from these acid treatments. Such sugars obtained as a by-product of the wood pulp industry in Europe are important in the production of alcohol and during World II were used to grow a yeast which supplied a protein supplement for the German army.

Industrial Utilization. Although considerable attention has been given to the potential utilization of *Arundo donax* for paper and dissolving pulps, only in one instance has this plant been used on a large-scale industrial basis. Prior to World War II, the Italian government encouraged the development of new sources of rayon pulp (4, 24, 26). This interest was stimulated primarily by the desire of the dictatorship to be independent of foreign sources of textile fibers and the desire for an export product. It was recognized that an immediate source of raw material was needed, that the designs of the dictatorship could not wait 20 to 30 years for the establishment of coniferous or deciduous tree plantations. Recognizing that annual crop residues could not be utilized, because of technical and economic problems, attention was directed to the development of a new crop as a source of industrial cellulose. Snia Viscosa, a large textile corporation, conducted a program of research on all materials that offered any potential for this purpose. As a result of this effort, *Arundo donax* was selected as the preferred species, because of its large yield, ease of preservation, and high content of top-quality cellulose.

Although later developments indicate that *Arundo donax* was not an economical source of pulp, the new venture was initiated with great enthusiasm. Plans were drawn up for the construction of a factory to use *Arundo donax* and for an accompanying plantation to supply the necessary raw material. Favored by the personal encouragement of the dictator Mussolini, work on this agricultural-industrial complex was initiated in 1937. A factory, town, and farm were established at a site later to be known as Torviscosa in the vicinity of Udine, Venezia Province, in northeastern Italy. The farm, established on land reclaimed from a marshy, previously uncultivated waste, originally covered 6,000 acres. By 1941, donax cane had been established on 7,500 acres, and plans called for a final holding of 15,000 acres to be in full production by 1943.

The establishment of new plantings and their maintenance apparently followed the methods developed by Onofry (27). This system consisted of dividing the fields into strips 2 m. wide, alternating with strips about 1.3 m. in width, each bordered by a drainage ditch .3 m. wide and .3 m. deep. Rhizomes were planted in east-west rows along the northern borders of the wide strips and were permitted to expand toward the south. In fields established on hillsides planting was arranged so that expansion would occur up-slope.

By the fourth year, the initially planted strips were densely covered with cane growth. Since the original rhizomes had become exhausted, cane production in the area initially planted had greatly diminished, and it was necessary to remove the dead growth.

In the following years, the young rhizomes were allowed to expand toward the south into fresh soil, and the exhausted rhizomes were removed from the opposite border of the strip. By the eighth year the cane shifted completely on to the strip that was originally bare.

This method of maintaining the fields allowed the cane to occupy only half the area during any one season, and the strips that were free of cane could be planted with legumes to improve the fertility of the soil.

The Onofry system was regarded as the most satisfactory for maintenance of high sustained yields. Production and quality of the cane were increased by greater exposure to the sun, improved drainage, higher soil fertility, and removal of exhausted rhizomes.

According to figures made public by Snia Viscosa, the average annual production at Torviscosa was 35 tons of green cane per acre (24). From this could be obtained 15 tons of dry cleaned cane which served as the raw material for the production of four to five tons of high quality dissolving pulp. This yield of pulp was considerably more than could be obtained from an acre of forest. The ultimate goal was to obtain from this one establishment a production of 65,000 tons of pulp per year, 40% of the total Italian requirement at that time.

In contrast with the yields cited above, natural stands of *Arundo donax* in India are reported to yield 3.2 tons of dry grass per acre yearly on a sustained-yield basis (32). In one area a plot of natural cane yielded five tons of dry grass per acre but this area was not fully stocked; the yield for a fully stocked area was considered to be six tons per acre. Another sample area yielded a phenomenal 43 tons per acre, but the crop consisted of many persistent bases of old culms and undoubtedly represented the growth of a number of years. In the United States, fairly good wild stands are reported to yield 8⅓ tons of oven-dry cane per acre; poorer stands yield 5¼ tons of oven-dry cane per acre (14).

Italian plantings, established with rhizomes, reached full production after three years and were expected to continue at full efficiency for at least ten years. Afterward, the fields were to be renewed by removal of the old rhizomes and replanted as necessary. The fertility would be restored in part by heavy applications of manure.

The cane was harvested during the winter and allowed to dry for several months in the open. At a later date, the harvest was collected in large piles and covered with cane in such a manner as to shed water. After seasoning for several additional months to assure a degree of uniformity, the raw material was transported to the mill as needed. At the mill, bundles of cane were crushed between rollers and then passed through a chipping machine to cut the culms into fragments about ¾ inch long. Seeds, leaf and sheath tissue, and a portion of foreign material were removed by machinery and returned to the farm to be used as bedding for cattle. The cleaned material was stored in large silos from which it passed to the boilers by gravity.

The cleaned chips were conveyed to boilers where the sugars were extracted with water at 100° C. The chips were then conveyed to storage bins above the digesters.

The extracted chips were cooked by the calcium bisulfite process in large stationary digesters to remove lignin and some other non-cellulose substance. The crude pulp was released into pits, washed, and passed to a machine to break up fiber aggregates and separate out the portion that was not sufficiently disintegrated. It was then passed into a separator, where sand and other heavy impurities were allowed to settle out. After washing, the pulp was cooked with mild caustic soda to remove silica and most other non-cellulose substances.

After again being washed, the pulp was subjected to a multi-stage bleaching process to remove the last traces of lignin. It was chlorinated, washed, and extracted with 10% caustic soda. Following an additional washing operation, the pulp was treated with hypochlorite bleach and given a final washing. The refined pulp was formed into sheets on a Fourdrinier-type machine. These sheets containing about 20% moisture were ready for use in the rayon mill.

The yield of refined pulp was claimed to have been 31%. The product was reported to have contained 97% alpha cellulose, 2.4% pentosans, and 0.1% ash.

The fibrous material that was not sufficiently disintegrated following the first cook and separated out before the second cook was used for the manufacture of wrapping paper.

Ethyl alcohol was a valuable byproduct of the industrial process. The hot-water extract obtained from the crushed chips was collected in large storage tanks from which it was drawn into other tanks where the sugar was fermented to alcohol. Distillation of the fermented extract yielded as much as 54 gallons of 95% ethyl alcohol for each ton of pulp produced. The cane was reported to contain 14% sugar (24).

Publicity associated with the opening of the factory and its 1940 expansion, in industrial and technical journals as well as in press notices, indicated that the industrial utilization of *Arundo donax* for rayon pulp by Snia Viscosa was highly successful and apparently economical. At that time, however, certain Italian sources of information indicated that the efforts to manufacture industrial cellulose from cane were almost a complete failure and that the factory in reality used timber imported from Yugoslavia. It was claimed that the cellulose produced was of inferior quality and was not accepted by rayon manufacturers as long as pulp was available from other sources. According to those reports, the cane pulp was used only by Snia Viscosa and its affiliates.

More recent reports indicate that, while the production of rayon pulp from cane never by any means approached the publicized goal of 65,000 tons per year, a considerable amount of this product was manufactured just prior to and during a part of World War II and probably for several years afterward. Recent reliable estimates indicate that production reached as high as 6,600 tons per year.

During the years immediately following World War II, Snia Viscosa is reported to have used 50% *Arundo* pulp and 50% imported Swedish wood pulp for the production of rayon.

At present, the Snia Viscosa factory at Torviscosa is the only establishment in Italy that utilizes cane for production of rayon pulp. Cane is currently used by this factory for the manufacture of about 4,400 tons of pulp each year. The principal raw material is now birch pulpwood imported from Yugoslavia.

The Torviscosa plantation has reduced the acreage of cane to 5,000 acres. This planting is maintained to serve as a supplementary source of raw material and provides a source of rhizomes for rapid extension of the acreage in the event that foreign supplies of raw material are cut off or become sufficiently expensive to justify the use of *Arundo donax*.

Excluding the effect of war-time conditions, the failure to attain the high goal of production of rayon from cane was due primarily to the high cost of producing and processing the raw material. A second factor that influenced production of this material was the marked decrease in demand for rayon in Italy during the post-war years. Prior to and during World War II the Italian government forced the consumption of rayon textiles and thus strongly prejudiced consumers against the product. Reaction against this policy resulted in decreased demand when United States financial aid made available large supplies of cotton after the war.

Arundo donax has recently been exploited as a source of paper pulp in Argentina. In 1952 a plantation of 5,000 acres was reported to have been established for this purpose at Ramallo. During that season an additional 1,700 acres were to have been planted. Establishment of the plantation followed the methods developed in Italy by Onofry (28). Additional information on this development is not available.

Ambitious plans were formulated in France in 1942 for the development of a domestic industry for the production of paper and dissolving pulp from *Arundo donax* (1). These plans called for the construction of a large factory and the planting of 12,000 acres of cane in southern France. In addition, the industry was expected to utilize cane from natural stands occupying more than 15,000 acres. The factory was to employ the methods used by Snia Viscosa and was expected to achieve a final capacity of 400 tons per day, approximately one third of the French requirement.

This industry did not become established, and with the end of the war the interest in substitute sources of raw material waned as imports of established raw materials became available. Recently, however, interest in this source of cellulose has again been indicated in France because of the shortage of foreign currency, which has resulted in a substantial decline in imports. This newly aroused interest is so recent, however, that no information is available on what path the industry will take.

Recent interest in cane as a source of pulp has been expressed in Yugoslavia (18). Apparently efforts in this area are still of an experimental nature.

Utilization: Minor Uses

Arundo donax is a very versatile material and has been widely utilized for a variety of purposes (10, 15, 21, 25). In many local areas, the plant has served many of the uses to which the bamboos are applied, within the limitations placed upon it by the smaller diameter of its culms. This species finds many useful applications in the vine and garden areas around the Mediterranean Sea. Many farmers maintain a small cane brake in order to be assured of their requirements, and the canes frequently enter commerce in times of local shortages. A large quantity of split culms are made into lattices for drying fruit and vegetables or woven into containers to be used for shipping these products as well as flowers and other materials. For lattices and basket work, young canes are preferred as they are more supple and easily worked. Canes are also used for garden fences and trellises, and for propping up vines and small trees, and the plants are often grown in hedge rows to serve as windbreaks. Leaves are used for tying up vines and other plants.

In Mexico, the canes are soaked in water and then crushed with a rock and woven into mats. The mats are used to construct chicken pens or to prevent the spillage of grain from box car doors.

In many areas where lumber is unavailable or obtained only at great expense, the culms are used in light construction. They serve well in the building of crude shelters and have limited application in the construction of permanent buildings. Mats formed from split culms are well suited for anchoring wall plaster, and the leaves serve as a satisfactory roof thatch. The canes are reportedly satisfactory for use as reinforcement in concrete. The culms are also utilized in the construction of furniture, particularly in the weaving of chair seats.

The culms are widely used for fishing rods and walking sticks and are reportedly used for pipe stems and in the construction of fish traps. Straight slender canes supplied arrows for the Egyptians, Greeks, and other early peoples. In areas where fuel supplies are limited, exhausted rhizomes are used for this purpose.

Employment of this plant for the control of erosion has received wide approval. It is used to advantage for this purpose along the banks of ditches and canals and in shallow drainage paths. The plant can be established in small torrents by staking large clumps of rhizomes to the ground and protecting them against the full rush of water with a covering of soil and straw or small brush (35). In Argentina the plant is recommended as a reinforcement for the edges of mountain terraces, and in Texas and Australia it is used for stabilizing drifting sands (42).

In Australia, donax cane is reportedly well suited as a source of fodder for livestock but the small, leafy, variegated strain is preferred (35). All livestock, including pigs and poultry, are attracted to it; when a horse or cow gains entrance to a garden in which this plant is growing, it is one of the first plants consumed. In the United States, cane is not considered very palatable to cattle but is grazed when other forage is not available (42). The plant is low in protein but has a comparatively high concentration of phosphorus in the upper portions even when grown on soils with an extremely low content of this mineral. Other investigators report that in Turkestan camels never touch this plant although they readily graze other coarse plants growing with it (29).

Medicinally the rhizome has been used as a sudorific, a diuretic, and as an antilactant and in the treatment of dropsy (21). Two alkaloids, gramine (donaxine) and donaxarine, have been isolated from the leaves (23, 29, 30). The former, originally isolated from barley, raises the blood pressure of dogs when administered in small doses. Large doses cause a lowering of the blood pressure of dogs.

During World War II, an American concern used small pieces of cane cut from defective woodwind reeds in the manufacture of certain scientific instruments. The combination of light weight and good mechanical strength readily adapted the material to this purpose.

In southern France, during World War II, large quantities of cane were woven into large mats and used to conceal roads and paths from enemy view.

Arundo donax has frequently been grown as an ornamental. The inflorescences have been dyed and used for decoration.

An early English patent covered the manufacture of a textile fiber from *Arundo donax* (15). The process called for splitting the culms into long strips by passing them between heavy rollers. After a treatment in caustic solution, fibers suitable for spinning were separated out by beating the material on wooden blocks. The fibers obtained were about 14 inches long and could be processed in the manner used for hemp.

Possibility of Industrial Utilization in the United States

The utilization of non-arboreous plants in the production of pulp creates many problems that place these materials in a disadvantageous position in relation to wood. Problems are created by their bulk and the necessity for their seasonal harvest resulting in greater expense of handling and storage. Pulping of these materials requires larger quantities of chemicals than does the pulping of wood and necessitates the employment of special methods. As an agricultural crop such plants must compete for space with other plants currently established in farming systems.

Arundo donax from natural stands is reported to be a satisfactory pulp source under conditions prevailing in India. The plant apparently shows promise as a satisfactory cultivated raw material in Argentina. In Italy, however, where considerable experience has been gained in the industrial cultivation of cane, the pulp industry relies on less costly imported pulps or pulpwoods.

Under the limitations of our present knowledge, non-arboreal plants when cultivated as a source of pulp are unable to compete with wood in well forested areas. Even in poorly forested countries, non-woody plants used for this purpose are obtained largely as agricultural residues or from natural growth.

Under present conditions, *A. donax* does not offer very much potential as a cultivated crop for the United States. However, among the non-woody, rapidly growing plants, this species is one of the highest producers of cellulose, and its present status will be altered as conditions of the pulp industry change. Increases in the cost of wood pulp will create a better competitive position for *A. donax* and other non-woody plants. The potential of cane as an industrial plant of the future is sufficiently great that some attention should be devoted now to research on its agronomic problems.

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