Medic, a forage legume that made good as an Australian immigrant, is going back home to Mediterranean cereal fields with the help of CIMMYT.

Squinting in the brilliant Tunisian spring sunshine, John Doolette scanned a long field of dark-green forage stretching a kilometer or two down one gentle slope and up the next. In the surrounding fields the sparse vegetation was turning brown and patches of red clay soil were conspicuous. But Doolette was not completely happy with the knee-deep growth of his forage demonstration field.

In cereal-legume rotations, medic boosts cereal yields by raising soil nitrogen and suppressing weeds while providing more and better feed for livestock.

“There haven’t been enough sheep on it,” he said. “They don’t have enough sheep.”

John Doolette is a CIMMYT forage expert. He has been working with Tunisian agriculturalists since 1971 in introducing a rotation of wheat and a forage legume to replace the wheat-fallow rotation most farmers now use. The lush field that sparked Doolette’s disappointment was a demon-
CEREAL LEGUME ROTATIONS: WHERE?

North Africa and the Mideast have perhaps 40 million hectares in fallow, but a substantial portion of that land is in areas climatically unsuited for medics. Dirk Leeuwrik of the Arid Land Agricultural Development Program has estimated the amount of fallow that could be put in medic almost immediately. He calculates that "the rotation could be introduced with a minimum of adaptive work and with maximum results" on 3 million hectares in six countries: Jordan, Syria, Lebanon, Tunisia, Algeria, and Morocco.

Leeuwrik's estimate is based on the amount of land in the six countries receiving 350 to 500 mm of rainfall and having no lower than 2°C average minimum temperature in the coldest month.

Then using data from Jordan which is more complete than data in most other countries, he estimated that fallow in the 350 to 500 mm zone was only 32 percent of the cropped land. By totaling the unirrigated land in winter crops in the previously defined ecological zone of the six countries and multiplying by one third Leeuwrik arrived at the 3 million hectares.

Although Turkey and Iran produce 60 percent of the wheat in the Mideast, Leeuwrik excluded them from his study because the extensive high-elevation areas that produce most of the wheat are too cold for annual legume varieties, he believes. Nevertheless, Leeuwrik sees a potential for medics around Khorramabad in Western Iran and around Qom in Northern Iran.

Other countries not considered in Leeuwrik's study were Libya, Cyprus, Israel, and Iraq. Leeuwrik finds a considerably greater long-term potential for annual legume rotations. They could, he says, "spread more widely to both lower and higher rainfall areas, particularly when a large range of locally adaptive [varieties] becomes available and . . . management techniques have been adapted to local conditions."

A study of Algeria by E.D. Carter, of the University of Adelaide, found a more extensive potential for cereal-legume rotations. Carter estimated that the rotation could be introduced on 2.5 million of the 2.7 million hectares now in fallow in Algeria over the next several decades. With a 1:1 cereal-legume rotation, that means that 5 million hectares in Algeria alone would be affected. This change, Carter says, would put the equivalent of US$45 million worth of nitrogen in the soil, it would double wheat yields, and it would allow twice as much livestock to be fed.

Weeds strangle productivity

The reason that CIMMYT, whose mandate is wheat and maize improvement, is promoting work on rotations lies in the tangled web connecting livestock and cereal production from Morocco to Iran. Many farmers in the region alternate a year of wheat, or barley, with a year of fallow (usually half the farm is in wheat and half in fallow). But the fallow fields are not bare—weeds sprout and farmers deliberately do not till the land to remove them. Owners of flocks of sheep pay the farmers for the right to graze the fallow fields. Some economists speculate that, considering the generally low cereal yields in the region, the farmer's income from selling grazing rights probably equals his income per hectare from growing wheat.

Allowing weeds to grow in the fallow year, however, contributes to the low cereal yields. The abundant weed seeds deposited in the soil during the fallow year sprout when the cereal crop is planted. The weeds then vie with the wheat plants for light, water, and nutrients. Moreover, if the farmer applies nitrogen fertilizer, fast-growing weeds such as wild oats benefit as much as the wheat and often smother the crop.

Thus severe weed infestations sabotage higher wheat production in the region in three ways: They compete with the wheat crop, they discourage farmers from applying nitrogen fertilizer, and they slow the adoption of new wheat varieties because weeds coupled with infertile soil cause the new wheats to give only marginally better yields than traditional wheats (the great incentive for switching to new wheats is the magnificent rewards they give to farmers who improve soil fertility and use better farming methods).

Medic—a neglected legume

The legume-wheat rotation envisioned by Doolette and David Saunders, a CIMMYT forage scientist who since 1973 has been working with the Algerian Ministry of Agriculture, is based on several annual species of Medicago that reseed themselves.

Annual Medicago—medics—are native to the Mediterranean basin. Although undesirable deep plowing suppresses them in wheat fields, they grow and reproduce along roadsides, despite the blazing heat of summer, the chill of winter, and the voracious grazing of sheep, goats, donkeys, and camels. Doolette and Saunders believe that properly managed medics could improve the fertility and water-holding capacity of the soil, combat weeds, control
erosion, raise wheat yields, boost livestock output, and indirectly reduce destructive cropping and overgrazing in rangelands. A large order for an obscure plant, perhaps. But for decades in Australia, medics, transplanted from their Mediterranean home, have been celebrated for just those characteristics.

Medic in Australia

Medics and subclovers (Trifolium subterraneum), another annual legume, arrived in Australia as stowaways aboard settler's ships in the 19th century. Ships carrying emigrants from England stopped in Spain and North Africa to buy hay for the livestock on board. Some of the hay contained medics and subclovers. The seeds of these crops voyaged to Australia and became established in the alien soil.

The medics and subclovers spread slowly, virtually unnoticed, under the Mediterranean-like climate of southern Australia until early in the 20th century. At this time, Australian farmers and scientists were becoming alarmed by steadily declining wheat yields. The thin soil was being exhausted by continuous, exploitive wheat growing. Scientists recommended a wheat-fallow rotation and the application of phosphorus fertilizer to revive the soil. Stimulated by the increasing use of phosphorus fertilizer in the 1920's, medics and subclovers flourished and spread rapidly—the medics especially in alkaline soils and the subclovers especially in acid soils.

Bare-fallowed soil was not, however, as successful as scientists had hoped in storing moisture under the blistering Australian summer and it was easily eroded by wind and rain. Moreover, the wheat-fallow rotation did nothing to prevent the loss of organic matter from the soil. Since decaying organic matter is a major source of soil nitrogen, soils low in organic matter tend to give low wheat yields.

In the 1930's scientists began to look closely at rotations involving nitrogen-fixing legumes. The medics and subclovers already growing wild throughout the Australian wheat belt were obvious candidates for the rotations. Scientists began to select and develop improved varieties from the ubiquitous wild species.

After World War II, legume-wheat rotations became commonplace on farms. One observer estimates that since then 60 to 70 percent of the total increase in Australian cereal yields has resulted from the use of legume rotations combined with application of phosphorus.

As consequences of the rich supplies of forage that wheat farms were producing, the traditional separation between wheat growing and sheep raising began to crumble, and Australia was able to begin a deliberate policy of reducing livestock and human population in the ecologically fragile arid and semi-arid zones.

Where medic fits

In North Africa the new wheat-legume rotation centers on medics rather than subclovers because the area's neutral to alkaline soils favor medics. John Doolette believes that soil pH (a measure of alkalinity or acidity) affects the growth of medics and subclovers through its influence on rhizobia—nitrogen-fixing bacteria—in the soil.

Piero Bronzi of the Ford Foundation and Norman Borlaug, director of CIMMYT's wheat program, look over an ungrazed field of first-year medic in Tunisia.
Rhizobia enter the roots of legumes where they benefit from sugars provided by the plant. Once in the roots, the rhizobia grow vigorously and convert atmospheric nitrogen into a form that the plant can use. The mutually beneficial relation of rhizobia and a legume plant is the classic example of symbiosis. But strains of rhizobia do not function equally well with all legumes—in fact the most suitable strain of rhizobia can differ from variety to variety within the same legume species. Apparently, then, rhizobia that live in alkaline soils are more compatible with medics, while rhizobia in acid soils are more compatible with subclovers.

Aside from soil pH, the geographic limits of medic growth are delineated by temperature patterns that are too cold or too warm and by insufficient rainfall. Frost or low temperature during the growing season reduces flowering or pollination so that seed production is inadequate. On the other hand, medics need a cold period during the growing season to induce flowering, hence uniformly warm temperatures also give poor seed production. Excessively dry weather lowers seed production by causing the florets to abort. While medics will grow in high rainfall areas, other crops often make better economic sense where water is abundant.

In the Mediterranean region, most observers believe that a cereal-medic rotation is best suited to the zone receiving 350 to 500 mm of rain annually. According to Dirk Leeuwrik of the Arid Lands Agricultural Development program in Beirut the coldest monthly average minimum temperature acceptable for medic growing is about 2°C.

In a study of the potential for livestock and cereal production in Algeria, sponsored by CIMMYT and the Algerian Ministry of Agriculture, E.C. Carter, of the University of Adelaide, says that the zone with over 600 millimeters of rainfall is generally too wet for cereals and should be used for livestock, especially dairy animals. The steppe zone—200 to 350 mm of rainfall—although currently cultivated in its wetter edges is too risky for cereal production and should be used for livestock breeding to stock the areas with above 350 mm of rainfall. Carter says.

The cold tolerance of medics becomes critical within the 350 to 500 mm rainfall zone at elevations above 600 meters. In Algeria a large share of the nation’s cereal production comes from the high plateau in the Atlas Mountains. Australian commercial medic varieties do not thrive there.

Nevertheless, Carter observes that in the high plateau “healthy medics and trifolium species can be found along the roadside that have survived frost, snow, and severe grazing.” Forage scientists believe that productive strains suitable for the high plateau can be selected from the species now growing there.

Fallow and its consequences

Bringing medics into the Mediterranean farming system could snap the chain of costly and sometimes unnecessary practices that now keep crop and livestock productivity low, and allow farmers to switch to more efficient methods.

At present, farmers have a third to a half of their land in fallow each year. If a farmer has a third in fallow it means on each field he is growing 2 years of wheat followed by 1 year of fallow. If he has half in fallow, he is alternating 1 year of wheat with 1 year of fallow.

During the fallow period, small amounts of nitrogen are released by decaying wheat stubble and dead weeds and by breakdown of minerals in the soil.

The slight accumulation of nitrogen which can be taken up by the subsequent wheat crop is the chief agronomic advantage of fallow in the Mediterranean region. Storage of water is often thought to be a benefit of the fallow period. But wheat planted in soils cropped since the age of the Phoenicians benefits little from rainfall during the fallow year. The poor structure of the soil allows rain to spill down the slopes. Whatever water trickles into the soil stays close to the surface because the soils are so thin. Then high temperatures and hot
winds during the summer evaporate most of the stored soil moisture before the autumn wheat-planting season.

Accepting the futility of hoping to conserve soil moisture, most farmers do not keep clean fallow fields: they allow weeds to grow. The weeds partially protect the soil from erosion by rain in the winter and by wind in the summer of the fallow year. The weeds also give the farmer a source of cash income when he rents his fallow fields to owners of flocks of sheep for grazing.

To prepare for planting wheat, most farmers use large disc and moldboard plows which turn the soil to a depth of 25 to 30 centimeters. This deep plowing is apparently an attempt to temporarily improve the structure of the soil—its clumpiness—before the wheat is planted. But in the long run it harms soil structure by dispersing the small quantities of organic matter which the soil contains.

Even with large tractors, deep plowing is slow and, hence, costly work. Moreover, farmers are often unable to plow all their fields while the soil is at its optimum moisture content. Plowing when the soil is too wet or too dry destroys the structure, leading to lower wheat yields. Late plowing also delays planting and the subsequent harvest, thus increasing the ripening crop's vulnerability to the hot winds which blow off the desert in the spring and which are a major cause of crop failure.

Deep plowing also explains why medic plants are scarce in most fields while the roadsides along the fields may be covered with medics. When medic seeds germinate deep in the soil, the seedlings are unable to reach the soil surface.

Unhappy returns
The consequences of the weed fallow return to haunt the farmer when the wheat is planted. The weeds that grew in the fallow year flowered and set seed, exploding the population of weed seeds in the soil compared with what it would have been in the absence of a weed fallow.

The weeds battle the wheat for nutrients, water, and sunlight. Sometimes weeds completely smother the wheat crop. A survey of 13 North African and Middle Eastern nations in 1975 concluded that weeds lower the region's wheat production by 20 percent—and the survey excluded fields that were abandoned because of weeds.

Weeds also reduce the potential returns from application of nitrogen fertilizer, which otherwise is the most profitable investment a small farmer who uses modern wheats can make.

Thus the Mediterranean wheat-fallow system with its costly and deleterious tillage, abundant weeds, low wheat yields, and periodic crop failure is ill-suited for stable agricultural production, and even less for keeping pace with rapid population growth.

Population pressure has forced farmers to plow the steppe land near the desert which is better left for grazing. While it is possible to harvest a crop of wheat or barley several times in a decade, wind and water erosion soon strips away the fragile steppe soil, leaving the land unfit even for grazing.

As rangeland shrinks, too many sheep graze too little land, contributing to the irreversible erosion of the steppe. The weed fallow in the cereal zone produces so little forage and the forage has such a low nutritive value that it cannot relieve the pressure on the low-rainfall rangelands near the desert.

The new rotation
The cereal-legume rotation attacks the agricultural problems of the region across a broad front. Here's how the rotation works. The basic pattern is one year of wheat (or barley) and one year of legume. But the farmer divides his land in half so
that he has a wheat crop in every year. That is, in any given year half the farmer's land is in wheat and the other half is in medic. In the next year, the land that was in medic is planted to wheat and the land that was in wheat grows medic.

The crop year begins in autumn when the first rains fall. The farmer tills the land that was previously in medic and plants wheat. On the land that was previously in wheat he spreads phosphorus fertilizer. The phosphorus stimulates fast growth by the legumes—medic—but it has little benefit for weeds, which are non-legumes. The medic quickly overshadows most weeds. In the year that the rotation is introduced to a farm, medic might be seeded, but once the rotation is established sufficient seed exists in the soil for the medic to regenerate itself.

During the year, medic is grazed carefully or cut for hay. Before planting wheat in the next crop season, the medic is grazed or cut close to the ground. In preparing the seedbed for wheat, the farmer keeps tillage shallow to avoid burying the medic seeds too deep. Most of the medic seed is "hard", that is, it won't germinate for over 12 months after it is set. The wheat crop benefits both from the nitrogen fixed by the medic a year earlier and from the low level of weeds since the medic has reduced the production of weed seeds in the previous year. After the wheat is harvested and after the dry summer season has passed, the

Schematic diagram of a fully established wheat-medic rotation. In each year the farmer has half his land in medic and half in wheat. Seed produced in the medic field in crop year X remains in the soil with little germination until year Z (in which the cropping pattern is a repeat of year X). Application of phosphorus on the wheat stubble stimulates rapid growth by the medic. Wheat benefits from nitrogen fixed by medic growth in the same field a year earlier.
farmer again spreads phosphorus on the wheat stubble. By now a large portion of the medic seed is “soft” and ready to germinate, and the rotation cycle begins again.

“Hard” seed
Hardseededness is a cornerstone of the wheat-medic rotation. Medic varieties must produce a high proportion of viable seeds that do not germinate for long periods. Most of the seeds must remain hard (unable to germinate) from the time they are set in the spring, through the long, hot, dry summer, through the whole wheat-cropping season with its rains and cool temperatures, through another summer, through the false starts of the following winter rainy season, and then germinate profusely when steady rains begin.

Hard seed in medic results from an impermeable seed coat; embryo dormancy does not play an important role. Layers of suberin deposited as the seed ripens and loses moisture to the air make the seedcoat impermeable. The proportion of hard seed depends on the stage of seed development when drying starts. Seeds that mature too quickly because of dry weather have less hardseededness.

The seed becomes permeable to moisture, and hence ready to germinate, through the action of daily temperature changes during the year. At the soil surface the difference between day and night temperatures often is as much as 40°C. As the temperature changes, the seedcoat expands and contracts until it cracks, allowing moisture to reach the embryo and start germination.

Ideally 85 to 95 percent of the seed would remain hard for over 12 months. The medic varieties Doolette and Saunders are working with have up to 85 percent hard seed. That amount of hard seed gives adequate medic stands in the regeneration year, nevertheless the CIMMYT scientists are looking for more hardseeded strains.

Phosphorus
Another essential of the rotation is the application of phosphorus. Doolette recommends spreading 25 to 45 kg/ha of $P_2O_5$ on wheat stubble when the first autumn rains fall. Without phosphorus the medic will have no advantage over weeds. Application of phosphorus not only encourages a thick medic stand that crowds out most weeds, it ensures that the plants are vigorous enough to fix large quantities of nitrogen.

Substantial changes will occur in the region’s use of phosphorus if the rotation becomes widespread. Dirk Leeuwrilk estimates that the 3 million hectares of potential legume pasture which he visualizes in six countries (See box: “Cereal-legume rotations: Where?”) would require those countries to increase phosphorus consumption by 50 percent. Fortunately, Morocco, Algeria, and Tunisia have large phosphorus deposits, while Jordan has smaller but adequate supplies.

Nitrogen
The nitrogen-fixing ability of medics in North Africa was a key question John Doolette had to answer when he began work in 1971. He already knew that medics could survive, but would they be productive nitrogen-fixers in the wheat-legume rotation? Indigenous medics, he found, were well-nodulated, that is, the roots had lumps indicating the presence of rhizobia. In addition soil conditions that impair good nodulation, such as low pH, and deficiencies of molybdenum, cobalt, and calcium, were not apparent in Tunisian soils. Together these points suggested that the soil would have adequate amounts of native rhizobia.

Trials in which he inoculated Australian medic varieties with commercially produced rhizobia and compared the forage yields with yields from the same varieties grown without commercial inoculum
showed that the native rhizobia were adequate for the two best varieties, Jemalong and Harbinger.

In subsequent rotation trials, wheat following medic produced yields equal to those of wheat fertilized with 60 kg/ha of nitrogen following wheat fallow. On 3 million hectares that amount of nitrogen would have been worth US$60,000,000 in 1975.

Shallow tillage
To prepare the soil for wheat, the medic stubble is tilled 8 to 10 cm deep after the first good rain in the autumn. This tillage is shallow enough to permit buried medic seed to germinate successfully a year later. Subsequent tillage to prepare a well-worked seedbed and to kill weeds that have germinated is made progressively shallower to avoid raising weed seeds to the surface.

Because the medic grown a year earlier improves soil structure and because the tillage is shallow, the land can be prepared faster. The farmer is better able to till all his wheat fields when the soil is at optimum moisture content and that also helps improve soil structure. The wheat-medic system thus replaces destructive tillage practices with constructive ones.

Grazing: a tool
Grazing by sheep or other livestock is a convenient way to manage medic stands, as well as a way of getting extra profit from the forage.

After wheat has been harvested, sheep should closely grazé the stubble during the summer and early autumn. Otherwise the stubble will insulate the soil from the wide temperature fluctuations needed to break down the hard medic seed in the soil.

Especially early in the season, grazing helps control weeds such as wild oats and ryegrass that respond to the nitrogen fixed by the medic. The sheep selectively eat out most grassy weeds which they find more palatable than the medic at this time.

Grazing increases medic seed set by shortening the plants. The stems of short medic plants have more nodes (joints), and since the flowers emerge from the nodes, the plants set more seeds.

In the summer and autumn before wheat is planted the dry medic residue must be grazed to the ground. The dry forage has high nutritive value for livestock and if left in the field it makes tillage for the wheat more difficult. In addition, bacterial processes that occur when the residue decays will temporarily make some soil nitrogen unavailable to the wheat crop.

Stocked with the proper number of sheep per hectare, medic fields produce more forage during the peak of the season than the sheep can eat. At this time hay can be cut and stored to feed later in the season when the medic is thin.

The lean period for sheep will be the 6 weeks after the rains start, says John Doolette. The previous season’s medic fields are being plowed for wheat, the current season’s medic fields are just starting to grow, and hay supplies are being exhausted. But after 6 weeks the new medic stands are usually flush enough to sustain the sheep.

Blanket recommendations for grazing management are impossible to give, Doolette says. Management must be adapted to the growth stage and the year’s weather. But, especially in the establishment year, grazing should be reduced while the medic is flowering. Otherwise the seed set will be reduced. Once the pods containing the seeds have formed and are falling to the ground, grazing causes no problem. The sheep ingest only a small proportion of all the pods in the field.

Launching an idea
When John Doolette arrived in Tunisia in 1971 he knew he couldn’t wait a decade or two to decide what type of rotation to introduce to farms. Yet standard rotation experiments take that long to be completed. “In comparing a simple 2-year rotation with 3-year rotation,” says Doolette, “and assuming each to have been established in 3 successive years to minimize the effect of climate in the year of establishment... the useful wheat yield data would be generated in the 9th, 10th, and 11th years of the experiment. It is not unusual to have analysis deferred until 25 to 30 years after the commencement in more complicated comparisons.”

Instead Doolette used what he calls “the best-bet approach” to decide what type of cereal-legume rotation to introduce. He carefully studied the environment, the constraints imposed by the environment, the management facilities, and the production goals and then looked to a similar region.
Inside tough seed pods, most medic seeds remain viable without germinating for 12 months or more. This "hard seed" characteristic permits a 1:1 rotation pattern—a year of medic and a year of wheat—in which the medic reseeds itself in the year after wheat from seeds set in the year before wheat.

in this case Southern Australia, for a suitable rotation system. Placing his chips on a 1:1 rotation of wheat and medic, Doolette then set up demonstration plots—adjacent half-hectare blocks of wheat and medic—on farms throughout Tunisia. At the same time, he established several types of replicated experiments that would yield information to adjust the rotation to Tunisian conditions.

The detailed experiments were set up in three ecologically different locations. A mini-rotation study compared the medic-wheat rotation with the fallow-wheat rotation in small (6 x 50 m) plots. A variety trial tested five medic varieties, each with and without rhizobial inoculation. A fertilizer trial established appropriate rates of phosphorus for medic. A management trial looked at alternatives in weed and insect control in medic, grazing management, and medic seed production.

The broad objectives of the detailed experiments and the demonstrations were to show the stability of the system—that the seed quality, seed hardness, and proper management would permit the medic to re-establish itself in the rotation—and to show that wheat yields could match those of wheat grown with fertilizers. And stemming from these two objectives was the goal of igniting the enthusiasm of farmers and agricultural officials.

More specific objectives were to find suitable varieties, to check the degree of hardseededness and nodulation, to identify potential problems such as harmful insects, to teach farmers and technicians, and to lay a basis for more detailed research.

How do you measure success in a rotation system? John Doolette's answer: "The system of rotation with annual medicago and wheat must allow the yield of cereals to be at least as high as that using the best available recommendations and permit livestock to be integrated." Doolette's experiments have shown that the nitrogen fixed by a first-year medic stand can produce wheat yields equivalent to those of wheat that has received 60 kg/ha of nitrogen fertilizer. He says, however, that it will take two or three cycles of the rotation before a proper micro-environment (adequate organic matter, good soil structure, high rhizobial population) is established which allows wheat yields to match those from fallow plus recommended rates of nitrogen fertilizer—in some soils as much as 150 kg/ha of nitrogen may be recommended.

In trials at 12 sites in Tunisia in 1974, wheat yields after first-year medic at eight of the sites were 90 percent or more of the yield of wheat after fallow, which had received recommended rates of nitrogen fertilizer. In trials with wheat after regenerated medic, yields were 90 percent or more of wheat with fertilizer at six out of eight sites.

MEDIC RESEARCH IN THE MEDITERRANEAN AREA

The largest cereal-legume rotation programs based on medic are in Tunisia and Algeria where CIMMYT forage scientists are working with officials of the ministries of agriculture. In 1975 Tunisia had 3000 hectares in medic and Algeria had 5000 hectares. Algeria plans to increase the medic area by 10 times by 1977. Already Algeria has 200 hectares of medic being grown for seed.

In Libya, a team of forage scientists from the South Australian government began work on mediccs in late 1974.

In other countries of the region, research on medics is almost nonexistent, although native medics have been collected in most areas.
Doollette expects to prove the worth of the rotation without counting the obvious benefits to livestock production. The rotation must function and be profitable even without animals, he says. Additional income from animal production is "cream on the jam."

Cuts of forage at two locations in Tunisia give an indication of the potential benefit to livestock. At St. Cyprien, first-year medic yielded 4.7 tons of dry matter per hectare, medic that regenerated after a wheat crop yielded 9.7 t/ha, and weed fallow yielded 3.2 t/ha. At Smindja the yields were: first-year medic, 2.8 t/ha; regenerated medic, 6.8 t/ha; weed fallow, 1.9 t/ha. These yields came from one cut made in the spring. Doollette emphasizes that in addition to having dramatically higher forage yields than weed fallow, the medic's thick, leafy stands give it better ability to recover after grazing.

Seeding in the first year
For farmers, the most alien idea in the medic-wheat rotation is applying phosphorus for winter pasture. To convince them that phosphorus application pays, the first-year medic stand has to be superb. While a less-than-dramatic first-year medic stand may be agronomically satisfactory, an unimpressed farmer may fail to apply phosphorus in subsequent years, he may be careless about grazing or mowing at the right time, or he may even plow up the field.

To ensure that the rotation starts off with a burst that commands the farmer's attention, the medic is seeded in the first year. After that the medic reseeds itself.

Until Tunisia (and other Mediterranean nations) develop medic varieties from indigenous wild medic and establish a medic seed industry (See box: "Medic seed industry"), the rotation must be initiated with medic varieties from abroad. During 1974 and 1975, Tunisia imported 60 tons of commercial medic seed from Australia, enough to start the rotation on 3000 hectares each year.

The two best Australian medic varieties for Tunisian conditions are Jemalong (*Medicago truncatula*) and Harbinger (*M. littoralis*). Jemalong is widely adapted, but does best in the zone of 400 to 500 mm of rainfall. It is tolerant of drought: it withstands moisture stress after germination and sets seeds well in spite of dry weather after flower-

Flushes of brilliantly colored flowers cascade across North African wheat fields delighting tourists but not farmers. The traditional cereal-fallow rotation keeps weed populations high.
MEDIC SEED INDUSTRY

A small medic seed industry is a logical future step for nations that introduce the medic rotation. Planting a hypothetical 3 million hectares in the Mediterranean and Mideast region would require 30,000 tons of medic seed worth US$45 million.

CIMMYT medic workers believe that the abundance of medic that can be found along roadsides, even in cold areas, indicates that a program of collection, testing and selection could lead to superior medic strains that could be released as varieties. A medic-breeding program is unnecessary.

Only a few farmers would be needed to multiply the seed; with yields of 500 kg/ha, 200 hectares would produce enough medic to start the rotation on 10,000 hectares a year. According to John Doolette, yields of up to 1000 kg/ha are possible with irrigation. Farmers who grow medic varieties for seed would need special seed-harvesting machinery and high level managerial skills to produce weed-free pure seed. But the rewards would be great. In Australia, growing 200 kg/ha of medic seed gives profits equal to those from growing wheat that yields 2000 kg/ha.

Neither variety can withstand extended cold or snow.

Seeding first-year medic requires carefully prepared soil. The seedbed must be shallow to minimize the amount of weed seeds brought to the surface where they could germinate and compete with the medic. An implement with tines, called the scarifier, scratches the soil surface leaving a seed-
In soil that contains native medic seed, a satisfactory “first-year” medic stand has been achieved by merely spreading phosphorus fertilizer to stimulate the medic plants into vigorous growth.

bed not more than 3-cm deep, which is sufficient for medics.

The seedbed should also be finely worked. Since medic seeds, like those of other legumes, are small, the soil particles of the seedbed must be small for good seed-soil contact. With close contact, the seeds germinate fast and the seedlings are better able to survive dry spells.

Medic can be seeded with a combined seed-fertilizer drill, or the medic seed and phosphorus fertilizer can be mixed and seeded through an ordinary fertilizer spreader. If seed and fertilizer are mixed, planting must take place the same day to keep the fertilizer from damaging the seed.

The recommended seeding rate is 10 kg/ha. This rate includes a safety factor which permits a good stand even if the seedbed is less than perfect and weeds are a problem. With well-prepared soil and no serious weed competition, 3 to 4 kg/ha of seed would be adequate.

Most of the seeds germinate in the seeding year because commercially processed seed has a low degree of hardseededness. The machinery used for harvesting and cleaning commercial seed cracks the seedcoat making it permeable to moisture.

The ideal time for seeding medic is after the first major rain. Seeding can be done in dry soil, but, Dave Saunders points out, since most of the seed is ready to germinate, a drought following a brief early-season rain may kill many of the seedlings. On the other hand, Saunders says, waiting
MEDIC AS A WEED

A weed, an old definition says, is any plant growing in the wrong place. To the extent that medic pasture uses moisture that might otherwise be stored in the soil for the wheat crop in the next season, medic could be considered a weed. But the argument is hard to support. Thin soils do not absorb much water during the rainy season and they do not retain moisture well through hot summer. In the long run, by improving the soil structure, medic pasture improves infiltration of water into the soil and the soil's water-holding capacity. So despite the use of water by medic, the net availability of stored soil moisture to the wheat plant is likely to rise over the years. Add to that the nitrogen-fixing ability of medic, and the conclusion must be that medic is not a plant in the wrong place.

Although some medic seed germinates when wheat is planted, it is rarely more than a mild nuisance. First, since no phosphorus is applied in the wheat year, any medic that germinates grows slowly while the wheat seedlings grow rapidly, benefiting from the nitrogen fixed by the previous year's medic pasture. Second, medic is a low-growing plant so that wheat plants easily overtop it. Third, unlike other weeds, medic, because it is a legume, does not compete with the wheat for soil nitrogen. Fourth, in the occasional field where medic seriously competes with wheat, the medic can easily be killed with a single application of 2,4-D, a commonplace, low-cost herbicide.

too long after the first major rain will reduce the medic's forage and seed production.

The primary goal of the first-year seeding is to establish large reserves of medic seed in the soil so that the medic will regenerate itself in later years. To increase flowering and seed set, the medic should be grazed or mowed to a height of 8 to 10 cm. At the time of flowering, grazing pressure must be reduced to allow seed set.

Forage is usually so abundant, even in the seeding year, that existing sheep flocks are too small to graze the medic down to the proper height. Thus most farmers have to use mowers to manage the pasture.

Mowers also are used to slice the tops off weeds in mid-season if there have been too few grazing sheep to eat out the grassy weed seedlings when they were succulent earlier in the season.

Properly managed medic produces more than enough seeds to regenerate itself. Reserves of medic seed in the soil reach 300 kg/ha after a few wheat-medic cycles. At 16 first-year sites in 1972/73 where John Doolette seeded medic, yields of pods (which contain the seeds) ranged from 270 to 3200 kg/ha.

Native medics respond

After the establishment year in some locations, Doolette has found that native medics, encouraged by the shallow tillage and the application of phosphorus, flourish and soon dominate the introduced medic variety. Since the ultimate goal is to get a thick stand of nitrogen-fixing plants, it makes little difference whether the medic pasture is composed of native or introduced strains.

It is possible to establish the medic rotation even without seeding. Shallow cultivation and the application of phosphorus stimulate the germination and growth of native medics. While the first-year stand is not as lush as a stand from seeded medic, in the regeneration year the stands are

THE AUSTRALIAN CONNECTION

When Keith Finlay began traveling as Deputy Director of CIMMYT in the late 1960's he was impressed, as many other plant scientists before him have been, by the unexploited agricultural potential of native medics and subclovers in North Africa. As an Australian, Finlay was acutely aware of the farming revolution that occurred in the Australian wheat belt when rotations based on medics and subclovers were introduced. Wouldn't similar cereal-legume rotations have great value in North Africa? He discussed the idea with the leaders of the CIMMYT wheat program and they thought it was worth investigating.

With funds from the Ford Foundation, CIMMYT hired John Doolette as a short-term consultant to examine the potential of rotations involving annual forage legumes in the Mediterranean region. Doolette had been working on rotation research in Australia since the 1950's.

After a 1-month survey trip in 1970, Doolette was cautiously optimistic that the rotations could fit the region's agriculture. Doolette's report encouraged CIMMYT to propose research on rotations to the Tunisian government and the Ford Foundation. An agreement was made and in 1971 Dolette was hired as a CIMMYT staff member assigned to work on rotations in Tunisia under a grant from the Ford Foundation.

In 1973 CIMMYT, the Algerian government, and the Ford Foundation made a similar agreement, and David Saunders, another Australian scientist with experience in cereal-legume rotations, joined the CIMMYT staff to work in Algeria.
equivalent. Yet, to convince the farmer that the novel management techniques pay off, the first-year stand must be impressive, so seeding is an essential part of selling the medic rotation.

Training
To spread the medic-wheat rotation rapidly, John Doolittle says, “we need to put plenty of feet in the field.” The training of tractor drivers is especially urgent. They must be taught the reasons for and the techniques of shallow tillage. Farmers will be forced to make many vital and unfamiliar decisions; they will need knowledgeable extension agents for assistance. And as medic pastures become widespread, livestock specialists will be needed to help farmers expand and manage flocks to make efficient use of the forage.

As a start, several young Tunisian and Algerian scientists have been sent to study cereal-legume rotations in Australia.

New equipment
The scarifier is important for preparing the shallow seedbed desirable for seeding first-year medic. Since a scarifier is basically a set of small shovels (tines) attached to a tool bar it would not be difficult for local implement manufacturers to produce it.

Rotary mowers or slashers are not unknown, but if medic became widespread many more would be needed. Mowers are essential for topping weeds and for chopping down wheat stubble. Even after sheep flocks have been built up, mowers will be a handy tool for pasture management.

The design of many other implements—seeders and plows, for example—could be improved to better fit the requirements of cereal-legume rotations, but existing machinery will serve if the operator has been trained. And without trained operators even the best machinery will fail.

Research needs
Dave Saunders believes the most critical medic research need is to select and test “cold tolerant, winter-vigorous local ecotypes.” Such medic varieties would open large areas of cereal production in high plateaus to the medic rotation.

As native strains are developed into varieties, research on the most productive rhizobia strains for them could be highly profitable.

Other desirable areas of research include studies on hardseededness of native strains; pasture management including fertilizer rates, grazing, cutting, optimum stocking rates, and grazing systems; agronomic studies of local crops and soil management; social studies related to integration of animal and crop enterprises; seed production.

Ripples of change
The wide adoption of cereal-legume rotations should create opportunities to halt the destruction of low rainfall zones. But it will require foresight and sensitivity on the part of national policy makers to ease the changes.

Grazing land at the margin of the desert is being turned into rocky wastes by cultivation and excessive grazing by sheep. In Algeria alone as much as 5 million hectares of steppe have been destroyed by cropping. Although techniques such as furrowing and pitting the soil to trap moisture for a few blades of grass can restore small areas, on a large scale the cost is too great. Rangeland lost is lost forever.

The productivity of the cereal-legume rotation

Native medic species can be found along roadsides throughout North Africa although they are often absent from adjacent cereal fields. This paradox underscores both the hardiness of medics and their vulnerability to unsound farming practices.
OTHER LEGUMES

Farmers around the world grow many types of forage legumes. Would some other legume fit into the Mediterranean farming system better than medic, especially in cold areas? Possibly, but most legumes cannot match medic’s strong points: high nitrogen fixation, ability to grow in low rainfall regions, and, above all, hardseededness.

A legume that lacks hard seed cannot re-establish itself in a wheat-legume rotation. It would have to be seeded anew after the wheat crop. While the ordinary farmer can save wheat seeds for the next planting, he is unable to harvest the tiny seeds of forage legumes. Hence the use of a legume that has to be seeded each year would require a large legume-seed industry.

Subclover is one legume that matches medics on almost all points, and unlike, medic, it thrives in acid soils. But the subclovers do not grow well in the neutral to alkaline soils that dominate the Mediterranean region.

Vetches (Vicia spp.) are the most often suggested alternative to medics in cold areas. Most, however, lack hardseededness. Another drawback is that many farmers harvest vetches for food which means that weeds get less competition. Furthermore, vetch is a little-studied crop while medic has been intensively investigated for several decades.

Everything considered, Doolette and Saunders believe that exploring the diversity of native medics that already grow in cold areas will be the fastest way to find a productive legume for those areas.

in higher rainfall zones should relieve the pressure on marginal lands. Dirk Leeuwrik estimates that the 3 million hectares suited for quick introduction of the rotation in Jordan, Syria, Lebanon, Tunisia, Algeria, and Morocco would safely permit a 25 percent increase in sheep flocks. In another study, E.D. Carter calculated that, ultimately, Algeria alone could have 2.5 million hectares in the rotation, permitting sheep flocks in the nation to double.

Simultaneously reducing pressure on the steppe and taking advantage of increased forage supplies in the cereal zone will require new and more stable forms of livestock management. At present, parasites, disease, and irregular feeding make the lambing percentage low. The weight of the sheep fluctuates widely with the availability of feed. Sheep are marketed irregularly and without planning. In the cereal zone, nomadic sheep ownership results in too many sheep on some fallow fields and too few on others.

Carter sees the need for a new relationship between the steppe and the cereal zone. The steppe should be a breeding area which annually sells young males and surplus ewes to farmers in the

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The Australian scarifier, right, easily prepares the 3-centimeter-deep seedbed desirable for seeding first-year medic. But tined implements, left, which are already fairly common in North Africa and the Mideast can be successfully used, too.
cereal zone. In the cereal zone the sheep would be fattened on the medic pasture and slaughtered.

This system would allow the size of flocks in the steppe to stabilize. At the same time it would allow grazing of pastures in the cereal zone to be more carefully controlled.

Carter says that pasture improvement must come before increase in livestock numbers. Building flocks will take time. In addition, a smooth flow of animals from the steppe zone to the cereal zone, and from the cereal zone to the cities demands better roads and bridges, livestock assembly points, credit agencies, selling associations—in other words, steps towards more efficient transportation and marketing networks. Hay will become an important commodity since some farmers that adopt the cereal-legume rotation will not have enough drinking water to maintain flocks of grazing animals.

Clearly, social problems arise in integrating livestock and cereal farming and in controlling nomadic grazing. Yet national populations are soaring and with the decline in availability of grazing land, continued unregulated nomadic grazing will inexorably lead to human problems that become harder to cure the longer they are ignored. Even now controlled grazing is not unheard of. The routine purchase of rights to graze weed fallow is one type of control.

A broadscale training program will be needed to develop technicians who can help farmers and sheep owners grapple with new problems such as marketing, livestock feeding, and pasture management.

The prospect
The introduction of cereal-legume rotations to Mediterranean climates has both radical and con-

servative aspects. The use of phosphorus on pasture, the new tillage techniques, the management of grazing animals are radical changes for the area. Yet the introduction of tractors and large plows transformed tillage practices in the Mediterranean basin decades ago. A change to less brutal tillage practices, while a new idea, is one that is more in harmony with the agro-climatic conditions of the area.

The conservative aspects of the new technology lie in the absence of need to introduce new crops or livestock. Wheat, medic, and sheep have existed in the region for millennia. None are alien to the landscape, and neither wheat nor mutton is strange on the dinner table. In addition, the practice of planting only part of the land in wheat and leaving the rest for “pasture” has always been widely used.

The wheat-legume rotation is also conservative in that it reduces the farmer’s risk while raising his opportunities for gain. The greater ability of the soil to absorb and hold water, lowers the farmer's vulnerability to drought. In a region where rain is highly erratic, the improved capacity of the soil to keep plants alive during droughts makes the odds on harvesting a crop much more favorable. Moreover, the nitrogen fixed by the medic allows the farmer to benefit from modern nitrogen-responsive wheat varieties without risking cash loss or putting himself in debt. If the weather is good, he reaps extra profits from the effect of the stored soil nitrogen on wheat yields. If the weather is bad, he may lose his crop but he has no cash investment in nitrogen fertilizer to lose as well.

The cereal-legume rotation is a bold, but calculated, stroke which promises to set in motion changes that could improve the lives of millions. Steven A. Breth