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China looks to sorghum for ethanol (Part 1)

China's sweet sorghum bio-ethanol program can have a sizeable impact on expanding the nation's feedstuffs availabilities as well as providing ethanol to blend with gasoline.

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CHINA, with one-fifth of the world's population and rapidly rising incomes, is a country that has naturally been open to speculation about its ability to feed itself and meet its energy needs over the next several decades.

Population is projected to grow from 1.28 billion in 2000 to 1.46 billion in 2020 and 1.49 billion in 2030. Simultaneously, per capita income growth will lead to greater demand for animal and fish products, thus resulting in expanded feedstuffs requirements.

China's rapid energy (such as electricity and gasoline) demand increase and extraordinary efforts to secure future sources are well known. What has not been studied, and is the focus of this article, is its bio-ethanol program and, in particular, the impact on the production of animal feedstuffs and human food.

This topic is of great importance for there is considerable concern among government leaders that bio-ethanol programs do not negatively affect the nation's food security. In fact, there is a policy that says, "Do not enter into rivalry with grain over land; do not enter into rivalry with farmers over grain."

Sweet sorghum and other materials such as sweet potatoes, cassava, sugarcane, etc., are the plant materials targeted for the bio-ethanol program rather than corn, which is the focus of the program in the U.S. (the world's largest producer of ethanol), or sugarcane in Brazil, the world's second-largest ethanol producer.

The research presented in this article evaluates the impact of the nascent sweet sorghum program by calculating the feedstuffs' nutrient-based energy and protein content derived from co-products of the bio-ethanol production process in five-year increments from 2005 to 2030. These results were further incorporated into a computer program covering all of China's crops, animals and human food to determine the impact on the nation's animal feedstuffs and human food production.

Research methods

A spreadsheet-based bio-ethanol co-product feedstuffs project planner was developed for analysis of the sweet sorghum program. These results were then integrated into a computer program especially developed for long-term projections of animal inventories, feedstuffs requirements and feedstuffs availabilities that was originally constructed by Simpson in the late 1980s and early 1990s. That long-term, non-deterministic simulation, spreadsheet-programmed model has been greatly revised and updated several times since then (Simpson and Li, 2001). All crops contain both energy and protein, and likewise, animals require both sources.

The method used in both programs is to calculate all requirements and availabilities on the basis of metabolizable energy (ME) and crude protein (CP). The analyses are based on energy and protein as the common denominator because it reduces a very complex problem to a much simpler one. A detailed explanation of the most recent results for China, including policy analysis, is also found in Simpson and Li (2004) and Simpson (2003, 2004 and 2006).

Sorghum as raw material

Sweet sorghum is a principal targeted bio-ethanol raw material as it can be produced on marginal land not currently used for crops such as alkaline and saline soils, in very low-rainfall areas where little or no irrigation water is available and in areas with climatic disadvantages.

About 7.3 million hectares of this type of land, scattered around China in a variety of eco-climates, have been identified as potentially available for sweet sorghum production. However, only about 22% (1.62 million hectares) is considered suitable for growing sweet sorghum as the other portion exceeds the salt-alkaline maximum of 0.6%. The modeling in this article is based on reaching the maximum of 1.62 million hectares in 2030.

Ethanol is produced from sugar. Thus, the objective in sweet sorghum breeding is to produce a plant that is high in sugar content, has an exceptional amount of biomass, is resistant to diseases, has a stalk that is easy to crush, is resistant to lodging, has extraordinary water use efficiency and has varieties that mature at different times to extend the milling process.

There are research stations in each eco-climate with programs on breeding improved varieties specifically adapted to that region. The principal provinces are Heilongjiang, Inner Mongolia, Qinghai, Shandong, Sichuan, Jiangsu and Xinjiang.

There are two types of sweet sorghum used for bio-ethanol: short and tall. China's focus is on the tall variety because it is higher yielding and more cost effective.

Research efforts using crossbreeding have resulted in a new sweet sorghum species called the "chun-tian series," which is high in sugar content and has cultivars that are early, middle and late maturing. Their development is considered a major accomplishment as this variety has improved resistance to dry conditions and is more tolerant of salt-alkaline conditions. Its growing period ranges from 116 to 125 days, making it suitable for all regions in which the effective accumulative temperature (above 10 degrees C) is more than 2,400 degrees C. Its stalk is 3-5 m in height and 2-4 cm in diameter. The stalk yield is 60-90 tons per hectare. Sugar content in the juice from the stalk is 15-21 degrees Bx.

Bio-ethanol projections

Three scenarios were evaluated in this analysis: (1) a base that forms the body of the next section, (2) the base scenario with greater treatment of bio-ethanol co-products for animal feed and (3) one in which none of the sweet sorghum grain is used as animal feed.

Ethanol production, land use

China produced 1.02 million tons of bio-ethanol only for fuel usage in 2005, 99% of which was from old stocks of raw material -- mainly corn, plus some wheat and other grains (Table 1). At a conversion rate of 3.1 tons of grain for one ton of bio-ethanol, 3.16 million tons of grain were required. That is equivalent to about 2.5% of China's corn production in 2005.

The government, cognizant of heavy pressures on arable land to meet human and animal food requirements, mandated that from the beginning of 2006, it was forbidden to use arable land to produce sweet sorghum for bio-ethanol production. It also emphasized that only non-grain raw material was to be developed for bio-ethanol production.

China's bio-ethanol program, as envisioned by the Committee of Biomass Energy Conversion Technology, which prepared the National Renewable Energy Development Projections, has projected 3.0 million tons of bio-ethanol to be produced in 2010, then greatly expanded to 6 million tons in 2015, 10 million tons in 2020, 12.5 million tons in 2025 and 15 million tons in 2030, the last year of projections (Table 1).

Sweet sorghum is projected to account for 17% of total bio-ethanol production in 2010, 40% in 2020 and 53% in 2030. Corn (and minor amounts of other grains) used for the nation's ethanol program (primarily from old stocks) is projected to remain at 1 million tons in keeping with the policy that grain production on arable land is not to be used for non-food uses. Other raw materials such as sweet potatoes, cassava, sugarcane, etc., are projected to account for 40% in 2030.

The committee's plan is that China's total gasoline use will reach 60 million tons annually by 2015 and that 10% will be a blend of bio-ethanol (Table 1). By 2020, total gasoline use is projected to be 65 million tons, and from there on, bio-ethanol will be blended at a 15% ratio. By 2030, when the sweet sorghum bio-ethanol program is at the highest point and gasoline use is projected at 70 million tons, 4.5 million tons of bio-ethanol are calculated to be available for export or additional blending with domestic gasoline.

China's bio-ethanol production projection for 2030 of 15 million tons can be grasped by comparing it with the U.S. situation. The U.S. produced about 11.6 million tons in 2006, and its Renewable Fuel Standard of the Energy Policy Act of 2005 mandates 21.8 million tons by 2012 (one metric ton of ethanol = 342 gal. of ethanol, and 1 million gallons of ethanol = 2,934 mt of ethanol).

The U.S.'s objective is to reduce dependence on foreign energy sources such as petroleum, and the same holds for bio-ethanol, although it imported about 1.5 million tons of bio-ethanol in 2006, albeit with a substantial import tariff of $170/mt (51 cents/gal.).

China's current national average yield per hectare of sweet sorghum is 4.1 tons of grain and 70 tons of stover (Table 1). Those yields were used for the entire projection period in the study as a conservative approach, even though it is recognized that they will increase -- perhaps significantly -- as varieties and management are improved.

Both the grain and stalk are used to produce bio-ethanol. The conversion rate to one ton of bio-ethanol is 3.1 tons of sweet sorghum grain (the same as corn) and 18 tons of stover (Table 1). The weighted average total bio-ethanol yield per hectare from sweet sorghum would be 5.2 tons per hectare (1.3 from its grain and 3.9 from stover) if all of the grain produced were used for bio-ethanol. However, the sweet sorghum grain has alternative uses.

It was assumed in the base projections that just 80% will be used for bio-ethanol, with the other 20% for other uses (such as livestock feed and drinking alcohol production). Consequently, the weighted average crop yield for the bio-ethanol program on all land planted to sweet sorghum from 2010 is 4.9 tons per hectare.

Land for sweet sorghum production is the limiting factor in the sweet sorghum bio-ethanol program since only 1.62 million hectares are available. As a comparison, that total is equivalent to about 1.1% of China's land now deemed arable and actually used for crops. About 30 million hectares are currently planted to corn.

Co-products

There are two co-products of China's sweet sorghum bio-ethanol: a residue of crushed stover after steaming by the solid fermentation method and stillage from the grain distillation process.

The quantity of harvested stover available for crushing will become quite large as the program expands, growing from 7 million tons in 2010 to 85 million tons in 2025 and 113 million tons in 2030 (Table 2). This magnitude can only be appreciated by recognition that China's entire stover production from arable land for 2030 (corn, sorghum and sunflower) is projected to be 200 million tons (Simpson and Li, 2004).

The conversion from field weight of sweet sorghum stover to residue after crushing is 22.5%. It is projected that 85% will be available for animal feed and 15% for non-agricultural uses such as making paper, particle board, fuel for heating, losses, etc. That translates to 1.4 million tons of residue fed to animals in 2010 and 21.6 million tons in 2030. In contrast, it is projected that 81 million tons of corn, sorghum and sunflower stover will be fed to animals in 2030 without the bio-ethanol sweet sorghum program.

There are two major ways to feed crop residues such as corn stover and rice straw, as well as the sweet sorghum residue: (1) directly as is (non-treated) and (2) treated to improve its digestibility and feeding value. The energy content of untreated sweet sorghum residue is 1.6 Mcal/kg; the treated residue is 2.4 Mcal (Table 2). That may not seem like much difference, but treatment provides an impressive 50% increase (treatment methods are discussed in Simpson and Li, 2001).

The protein content of untreated sweet sorghum residue is 3.56%, and treated it is 5.50% -- a 54% gain. In brief, management and use of the residue is of great importance in bio-ethanol co-product use. As such, appropriate national-level policies are vital to guide this developing sub-industry and effectively utilize it in rural restructuring programs.

There are two related terms for co-products of bio-ethanol production. One, non-conventional feed resources (NCFR), is used for those agricultural commodities that are not bought and sold on the open market such as waste from processed foods, water weeds, straw, stovers, etc. Residue from the sweet sorghum stover after the distillation process is an NCFR.

The agricultural commodities commonly sold on the open market are termed byproducts. The residue from the distillation tower of sweet sorghum grain to bio-ethanol is a fermented mash called stillage. From that, a byproduct called distillers grains is produced that can be directly fed to animals -- wet distillers grains (WDG) -- or it can be dried to make distillers dried grains (DDG). DDG is a common, internationally traded byproduct.

WDG has the disadvantage that its quality quickly declines; it is also quite bulky and, thus, costly to transport (e.g., Hart and Carriquiry, 2007). Consequently, it is almost exclusively used for local feeding, mainly to cattle. Calculations in the study were based on 50% of the grains destined for animal feed being fed directly as WDG and 50% as DDG.

Both wet and dried distillers grains have a relatively high protein content. The dried grains are 28.8% protein (about half that of fish meal, one of the highest protein byproducts used for animal feed). DDG is increasingly being included in diets for all animals and fish in the U.S. (as evidenced by a growing number of articles in *Feedstuffs*).

It is common to add micro products called solubles to DDG, and that product is known as distillers dried grains with solubles (DDGS). Just 100,000 tons of WDG and 50,000 tons of DDGS are projected to be produced from sweet sorghum in 2010 (Table 3). Output of the two will jump to 1.59 million tons and 0.85 million tons, respectively, in 2030. In contrast, 1.0 million tons of DDGS are projected to be produced annually over the entire projection period from corn used to produce bio-ethanol (Table 4).

Total ME, CP

Sweet sorghum is projected to account for 46% of all ME from a combination of both sweet sorghum and corn (including other grains, such as wheat) in 2010. That share leaps to 77% in 2015 and 93% in 2030 (Table 5). The proportion of CP from sweet sorghum is calculated to be 22% in 2010, 53% in 2015 and 82% in 2030.

It is projected that 2.6 billion Mcal of animal feedstuffs will be produced from sweet sorghum sources in 2010, increasing to 41.4 billion Mcal in 2030 (Table 5). (One kilocalorie, or Kcal, equals 1,000 small calories. One megacalorie, or Mcal, is equivalent to 1,000 kcal. A way to conceptualize the 41.4 billion Mcal is that adult cattle require about 4,000 Mcal annually. The sweet sorghum output is enough to feed about 10 million adult cattle for one year. China is projected to have about 130 million cattle of all ages at that time.) CP output from sweet sorghum is calculated to grow from 81,000 tons in 2010 to 1.3 million tons in 2030. The residue from stover accounts for 88% of ME and 63% of CP in all years from 2010, which is not unexpected considering the huge tonnage from the stalk.

ME, CP comparison

The sweet sorghum bio-ethanol program will contribute significantly to the totality of feedstuffs produced in China and to the nation's ability to feed itself.

Virtually no impact is expected in 2010 as the program begins to shift from the pilot to commercial stage. However, in 2020, the ME output from sweet sorghum is calculated to be equivalent to 1.2% of all of China's feedstuff availabilities without sweet sorghum and 2.1% by 2030 (Table 5).

In effect, using marginal land (not currently classified as arable land) for sweet sorghum is comparable to adding 2.1% more ME to national availabilities in 2030. The additional protein feedstuff availability equivalency is slightly less at 1.6% in 2030.

Table 6 contains long-term projection program results on a total ME and CP basis for the entire country. The first part, labeled arable land only, does not include the sweet sorghum bio-ethanol program.

That difference between supplies and requirements of 390,782 billion Mcal in the 1999-2001 base period is a gap of 25% more calculated requirements than calculated availabilities. This "gap" is expected; the discrepancy is not large and is well within an acceptable amount. The gap exists because data are not available on many feedstuffs actually consumed such as table scraps from residences, garbage from restaurants, unutilized nutrients eaten by free-range poultry and other animals, roadside and other grazing, unreported non-conventional feedstuffs such as water plants fed to pigs, grasses and weeds fed to pond-raised fish and simply misspecifications and unreliability of data.

The 25% gap for ME and 24% gap for CP in the 1999-2001 base period serve as baselines. China can be considered to have been in an equilibrium situation at that time regarding animal feedstuffs as animals (including fish) were not generally malnourished, although many were on a less than satisfactory plane of nutrition. Projections to 2030 include additional feedstuffs intake as the plane of nutrition grows commensurate with improved management, technology adoption and economic development.

A decline in the gap means a surplus is being generated, which in turn implies that the extra crop production could be used to increase domestic stocks, it could be exported or policies could be enacted to allow shifts in production between crops. Conversely, an increase in the gap means a deficit is being created that will have to be met with imports of either feedstuffs for animals or increased imports of food for humans.

Clearly, there will be changes and adjustments to agricultural and other policies as time passes in response to fluctuations in the gap. The projection program is a simulation and not a forecasting model.

The gap is based on the parameters chosen for per capita consumption of the various animal products, changes in diet, population growth, changes in crop yields and land allocation and technological changes in animal production (Simpson and Li, 2001 and 2004). The gap in energy requirements over availabilities with the sweet sorghum program declines continuously over the entire projection period -- to 21% in 2010, 16% in 2020 and 11% in 2030, indicating a growing surplus of energy.

The gap is an intuitive and easy-to-understand measure. However, even though the gap declines, the absolute amount of requirements over availabilities can actually increase because the size of both requirements and availabilities grows.

Such is the case in 2010, at which time it grows by 10,200 billion Mcal. From this point, the discussion focuses on the change in availabilities over the base period gap (last line of ME and CP sections in Table 6) as that measure provides a truer picture of the changes in surplus and deficits. There is a 3% increase (shown as -3) in the additional requirements with the sweet sorghum program in 2010 over the base period. That means a deficit of 3% without the program.

The interpretation is that a slight shortfall in ME might take place that year (or more realistically about that time). In practicality, that gap is really quite minor and can be misleading considering China has continued to either export corn, or at least not import it, and has even committed 1 million tons of corn and other grains to bio-ethanol production since 2005.

The more important way to analyze the data in Table 6 is by focusing on longer-term changes. The important results for the sweet sorghum program impact start in 2020, when the change in ME availabilities over the base period gap becomes 11%, meaning a surplus is growing. It would have been 6% without the program. The surplus grows to 145,040 million Mcal in 2030 to become a 37% over the base. It would have been 27% without the program. At first blush, that difference may not seem like a lot, but it is a 40% increase.

The results reveal that quite a large surplus would occur unless policies are adopted to prevent it. Some examples are shifts in crops, using less NCFR such as stovers for feeding animals and reducing some poorer-quality arable land for crops. Changing economic conditions will also lead to market place corrections.

China's protein deficit is projected to grow with or without the bio-ethanol program. Without the program, the changes in availabilities over the base period gap point to an increasing deficit of 39% in 2020 and 39% in 2030. With the sweet sorghum program, those percentages are projected to be 35 and 31%. The 2030 sweet sorghum level is 21% lower than the arable land-only option.

China has continually increased imports of soybeans and other protein sources, and calculations show that the trend will continue. In the 1999-2001 period, net imports of oilseeds were about 14 million tons annually and protein-based meal imports, mostly soybean meal, about 2.5 million tons.

A half-decade later, imports of soybeans had reached about 25 million tons, and projections by Simpson, not including the bio-ethanol program, are that additional imports above the base level of 14 million tons could reach between 35 million and 80 million tons by 2030, depending on assumptions about animal product consumption and changes in the quantity of crop residues treated to enhance their quality. The crux of the analysis on protein is that by 2030, China has the potential to reduce imports of protein-oriented feedstuffs by about 21% due to the sweet sorghum program so that the range of soybean equivalent imports could be 28 million to 63 million tons rather than 35 million to 80 million.

Three key points emerge from this section. First, the sweet sorghum bio-ethanol program (plus the other bio-ethanol crop raw materials) have a very important to role play in the extent to which China will have to import commodities to meet protein shortfalls for animal feedstuffs. Second, as shown by the very large range in projections of soybean equivalent imports, assumptions about human diets and treatment of NCFR are quite sensitive.

The lower level of imports is based on per capita beef consumption of 8 kg and treating 60% of all corn stover to improve its quality and feeding it to animals. The higher level is based on per capita consumption of 10 kg of beef and treating just 35% of corn stover to feed to animals. Third, policy decisions about how NCFR and byproduct feedstuffs are utilized have an incredible importance to China's ability to maintain its current 95% food self-sufficiency level.••••

In brief, China is projected to potentially have substantial energy surpluses without the bio-ethanol program and very large potential ones with it. However, substantial and growing protein imports will be required unless alternative sources become available, and that is where co-products from the sweet sorghum bio-ethanol program (and other raw material co-products) -- and policy decision on them -- enter into play.

Sensitivity analyses

There are myriad sensitivity analyses that could be undertaken, but only two have been chosen: (1) changing the treatment level of stover residue fed to animals and (2) sweet sorghum grain being used for purposes other than making bio-ethanol. The results in this section are all for the projection year 2030 as that is when the maximum amount of land available for sweet sorghum production is projected to be used.

Treatment of stover residue

The assumption in the sensitivity analysis on treating stover residue is that 100% be treated (to improve its palatability and quality) rather than 10% in the base scenario. The result is that total energy (ME) from the sweet sorghum stover residue would increase 43% and protein (CP) 47% (Table 7).

The effect at the national level of increased treatment is that the contribution of sweet sorghum increases from 2.10 to 2.90%. That is an additional 38%. The benefit on CP availabilities is a 29% increase from the base scenario, as the sweet sorghum contribution to ME of all arable land crops would expand from 1.56 to 2.02%.

If all sweet sorghum stover residue were treated, the nation's surplus ME in 2030 over the base period would expand 11% -- from 37% to a whopping 41%. The country's CP deficit would decline 8%, from -31 to -29%.

The conclusion is that treating for quality and palatability improvement is a proven technology that has considerable economic benefit to users as well as substantially reducing protein equivalent imports.

1. China's per hectare and land requirement calculations and bio-ethanol production, 2005-30

Item	2005	2010	2015	2020	2025	2030
Basis calculations, raw material yield per hectare (tons)						
Corn and wheat (grain)	4.2	4.7	5.1	5.8	6.2	7.0
Sweet sorghum (grain)	4.1	4.1	4.1	4.1	4.1	4.1
Sweet sorghum (stover)	70.0	70.0	70.0	70.0	70.0	70.0
Conversion, one ton raw material to tons of ethanol						
Corn and wheat (grain)	3.1	3.1	3.1	3.1	3.1	3.1
Sweet sorghum (grain)	3.1	3.1	3.1	3.1	3.1	3.1
Sweet sorghum (stover)	18.0	18.0	18.0	18.0	18.0	18.0
Bio-ethanol yield per hectare if all used for bio-ethanol (tons)						
Corn and wheat (grain)	1.4	1.5	1.6	1.9	2.0	2.3
Sweet sorghum (grain)	1.3	1.3	1.3	1.3	1.3	1.3
Sweet sorghum (stover)	3.9	3.9	3.9	3.9	3.9	3.9
Total, sweet sorghum	5.2	5.2	5.2	5.2	5.2	5.2
Bio-ethanol yield per hectare based on model (tons), sweet sorghum						
Proportion of grain used for bio-ethanol (%)	0.0	80.0	80.0	80.0	80.0	80.0
Bio-ethanol from grain (tons)	0.0	1.1	1.1	1.1	1.1	1.1
Bio-ethanol from stover (tons)	3.9	3.9	3.9	3.9	3.9	3.9
Total bio-ethanol yield per hectare (tons)	3.9	4.9	4.9	4.9	4.9	4.9
Bio-ethanol production by source (million tons)						
Sweet sorghum	0.00	0.5	2.0	4.0	6.0	8.0
Corn and grains	1.02	1.0	1.0	1.0	1.0	1.0
Other material (sweet potato, cassava, sugar cane, etc.)	0.00	1.5	3.0	5.0	5.5	6.0
Total	1.02	3.0	6.0	10.0	12.5	15.0
Proportion of bio-ethanol production by source (%)						
Sweet sorghum	0.0	16.7	33.3	40.0	48.0	53.3
Corn and grains	100.0	33.3	16.7	10.0	8.0	6.7
Other material (sweet potato, cassava, sugar cane, etc.)	0.0	50.0	50.0	50.0	44.0	40.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Land required for bio-ethanol production (mil. hectares), sweet sorghum						
Land available	1.62	1.62	1.62	1.62	1.62	1.62
Calculated land use	0.00	0.10	0.40	0.81	1.21	1.62
Land over or under available	1.62	1.52	1.22	0.81	0.41	0.00
Automobile and other gasoline-like fuel						
Total gasoline required (mil. tons)	50.0	55.0	60.0	65.0	70.0	70.0
Proportion available by bio-ethanol (%)	2.0	5.5	10.0	15.4	17.9	21.4
Proportion desired from bio-ethanol (%)	2.0	5.4	10.0	15.0	15.0	15.0
Bio-ethanol required for domestic use (mil. tons)	1.0	3.0	6.0	9.8	10.5	10.5
Bio-ethanol for exports or other uses (mil. tons)	0.0	0.0	0.0	0.3	2.0	4.5

2. Animal feedstuffs available from sweet sorghum stover in China, 2005-30

Item	2005	2010	2015	2020	2025	2030
Total stover produced (mil. tons)	0	7	28	57	85	113
Conversion sweet sorghum stover (wet basis) to ethanol residue (dry basis), %	22.5	22.5	22.5	22.5	22.5	22.5
Bio-ethanol residue from sorghum stover (mil. tons)	0.0	1.6	6.4	12.7	19.1	25.5
Residue proportion used for animal feed (%)	85	85	85	85	85	85
Bio-ethanol residue for animal feed (million tons)	0.0	1.4	5.4	10.8	16.2	21.6
Treatment of sorghum stover ethanol residue (%)						
Untreated	90	90	90	90	90	90
Treated	10	10	10	10	10	10
Total	100	100	100	100	100	100
Sorghum stover ethanol residue fed to animals (mil. tons)						
Untreated	0.0	1.2	4.9	9.7	14.6	19.5
Treated	0.0	0.1	0.5	1.1	1.6	2.2
Total	0.0	1.4	5.4	10.8	16.2	21.6
ME sweet sorghum residue, feed composition						
Untreated (Mcal/kg)	1.6	1.6	1.6	1.6	1.6	1.6
Treated (Mcal/kg)	2.4	2.4	2.4	2.4	2.4	2.4
Total sweet sorghum residue ME available to feed						
Untreated (mil. Mcal)	0	1,948	7,794	15,588	23,382	31,176
Treated (mil. Mcal)	0	325	1,299	2,598	3,897	5,196
Total (mil. Mcal)	0	2,273	9,093	18,186	27,279	36,371
CP, feed composition						
Untreated (%)	3.6	3.6	3.6	3.6	3.6	3.6

Treated (%)	5.5	5.5	5.5	5.5	5.5	5.5
Total sweet sorghum residue CP available to feed						
Untreated (1,000 tons)	0	43	173	347	520	694
Treated (1,000 tons)	0	7	30	60	89	119
Total (1,000 tons)	0	51	203	406	610	813

3. Animal feedstuffs available from sweet sorghum DDG in China, 2005-30

Item	2005	2010	2015	2020	2025	2030
Sweet sorghum grain produced (mil. tons)	0.00	0.41	1.66	3.32	4.97	6.63
Proportion to bio-ethanol (%)	0	80	80	80	80	80
Grain used for bio-ethanol (mil. tons)	0.00	0.33	1.33	2.65	3.98	5.30
Conversion rate, grain to pressed residue (%)	60	60	60	60	60	60
Total distillers pressed grains	0.00	0.20	0.80	1.59	2.39	3.18
Use of distillers grains						
Proportion WDG of pressed residue (%)	50	50	50	50	50	50
Conversion rate pressed residue to WDG (%)	100	100	100	100	100	100
Total WDG (mil. tons)	0.00	0.10	0.40	0.80	1.19	1.59
Proportion DDGS of pressed residue (%)	50	50	50	50	50	50
Conversion rate grain to DDGS (%)	32	32	32	32	32	32
Total DDGS (mil. tons)	0.00	0.05	0.21	0.42	0.64	0.85
ME from distillers grains						
Feed composition of WDG (Mcal/kg, estimated)	1.50	1.50	1.50	1.50	1.50	1.50
Total ME (mil. Mcal)	0	149	597	1,193	1,790	2,387
Feed composition of DDGS (Mcal/kg)	3.07	3.07	3.07	3.07	3.07	3.07
Total ME (mil. Mcal)	0	163	651	1,303	1,954	2,605
Total ME (mil. Mcal)	0	312	1,248	2,496	3,744	4,992
CP from distillers grains						
Feed composition of WDG (%) 15.00	15.00	15.00	15.00	15.00	15.00	
Total CP (1,000 tons)	0	15	60	119	179	239
Feed composition of DDGS (Mcal/kg)	28.80	28.80	28.80	28.80	28.80	28.80
Total CP (1,000 tons)	0	15	61	122	183	244
Total CP (1,000 tons)	0	30	121	242	362	483

4. Animal feedstuffs available from corn and wheat DDGS in China, 2005-30[1]						
Item	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Total grain production (mil. tons)	3.16	3.10	3.10	3.10	3.10	3.10
Conversion rate, corn grain (wet basis) to DDGS (%)	32	32	32	32	32	32
Feedstuffs available to animals from DDGS (mil. tons)	1.0	1.0	1.0	1.0	1.0	1.0
ME DDGS						
Feed composition (Mcal/kg)	3.07	3.07	3.07	3.07	3.07	3.07
Total ME (mil. Mcal)	3,106	3,045	3,045	3,045	3,045	3,045
CP DDGS						
Feed composition (%)	28.8	28.8	28.8	28.8	28.8	28.8
Total CP (1,000 tons)	291	286	286	286	286	286
[1]Corn used for calculations.						

5. ME and CP from bio-ethanol program and comparisons with all crops produced in China, 2005-30						
Item	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Total feedstuffs from all crops available to feed (summary)						
ME (mil. Mcal)						
Sweet sorghum stover	0	2,273	9,093	18,186	27,279	36,371
Sweet sorghum grain	0	312	1,248	2,496	3,744	4,992
Total sweet sorghum ME available to feed	0	2,585	10,341	20,682	31,023	41,364
Corn and wheat	3,106	3,045	3,045	3,045	3,045	3,045
Total all crops ME available to feed	3,106	5,631	13,386	23,727	34,068	44,409
CP (1,000 mt)						
Sweet sorghum stover	0	51	203	406	610	813
Sweet sorghum grain	0	30	121	242	362	483
Total sweet sorghum CP available to feed	0	81	324	648	972	1,296
Corn and wheat	291	286	286	286	286	286
Total all crops CP available to feed	291	367	610	934	1,258	1,582
Proportions of ME and CP from sweet sorghum (%)						
Stover ME	0	88	88	88	88	88
Grain ME	0	12	12	12	12	12
Total sweet sorghum ME available to feed	0	100	100	100	100	100
Stover CP	0	63	63	63	63	63
Grain CP	0	37	37	37	37	37
Total sweet sorghum CP available to feed	0	100	100	100	100	100
Sweet sorghum proportion of total available to feed (%)						
ME	0	46	77	87	91	93

CP	0	22	53	69	77	82
Sweet sorghum compared with all crops in China						
ME availabilities						
Arable land, without sweet sorghum (mil. Mcal)		1,504,373		1,755,578		1,967,184
Sweet sorghum (mil. Mcal)		2,585		20,682		41,364
Sweet sorghum of arable land (%)		0.2		1.2		2.1
CP availabilities						
Arable land, without sweet sorghum (1,000 mt)		64,110		73,838		82,979
Sweet sorghum (1,000 mt)	816481,296					
Sweet sorghum of arable land (%)		0.1		0.9		1.6

6. ME and CP requirements and availabilities for animals and fish in China, with and without sweet sorghum, 2000-30

Item	Avg. 1999-2001	2010	2020	2030
	-ME, mil. Mcal-			
Arable land only				
Requirements, all animals and fish	1,575,612	1,907,940	2,124,156	2,254,289
Availabilities, arable land only	1,184,830	1,504,373	1,755,578	1,967,184
Gap in requirements over availabilities	390,782	403,567	368,579	287,105
Change in the gap over the base year	--	-12,786	22,203	103,676
Arable land plus sweet sorghum				
Availabilities from sweet sorghum	0	2,585	20,682	41,364
Total availabilities, arable land and sweet sorghum 1,184,830	1,506,958	1,776,259	2,008,547	
Gap in requirements over availabilities	390,782	400,982	347,897	245,741
Change in the gap over the base year	--	-10,200	42,885	145,040
Arable land only	-%-			
Increase over base year				
Requirements, all animals and fish	--	21	35	43
Availabilities, arable land only	--	27	48	66
Change in availabilities over base period gap	--	-3	6	27

Arable land plus sweet sorghum				
Gap in requirements over availabilities	25	21	16	11
Change in availabilities over base period gap	--	-3	11	37
Arable land only	-CP, 1,000 mt-			
Requirements, all animals and fish	68,254	84,154	96,218	105,365
Availabilities, arable land only	52,189	64,110	73,838	82,979
Gap in requirements over availabilities	16,065	20,045	22,381	22,386
Change in the gap over the base year	--	-3,980	-6,316	-6,321
Arable land plus sweet sorghum				
Availabilities from sweet sorghum	0	81	648	1,296
Total availabilities, arable land and sweet sorghum	52,189	64,191	74,486	84,275
Gap in requirements over availabilities	16,065	19,964	21,733	21,090
Change in the gap over the base year	--	-3,899	-5,668	-5,026
Arable land only	-%-			
Increase over base year				
Requirements, all animals and fish	--	23	41	54
Availabilities, arable land only	--	23	41	59
Change in availabilities over base period gap	--	-25	-39	-39
Arable land plus sweet sorghum				
Gap in requirements over availabilities	24	24	23	20
Change in availabilities over base period gap	--	-24	-35	-31
Source: **Simpson, modeling results.**				

7. Sensitivity analyses of China's sweet sorghum program, 2030					
	Base	**Base scenario**	**No grain**	**-Diff. from base scenario-**	
Item	**scenario**	**and treatment**	**used**	**Treatment**	**No grain**
Parameters with changes					
Stover residue treated to improve quality (%)	10	100	10		
Grain for bio-ethanol (%)	80	80	0		
Land required for sweet sorghum	1.62	1.62	1.62		
Bio-ethanol production (mil. tons)	8.00	8.00	6.29	0	-21

Stover products only					
Stover (mil. tons)	113.2	113.2	113.2	0	0
Residue for animal feed (mil. tons)	21.6	21.6	21.7	0	0
ME (mil. Mcal)	36,371	51,959	36,378	43	0
CP (1,000 mt)	813	1,191	813	47	0
Grain products only					
Produced (mil. tons)	6.63	6.63	6.63		
Used for bio-ethanol	80	80	0		
WDG produced (mil. tons)	1.59	1.59	0		
DDG produced (mil. tons)	0.85	0.85	0		
Total nutrients produced					
ME (mil. Mcal)	4,992	4,992	0		
CP (1,000 mt)	483	483	0		
Sweet sorghum compared with all crops on arable land					
ME availabilities, stover and grain					
Arable land crops without sweet sorghum (mil. Mcal)	1,967,184	1,967,184	1,967,184		
Sweet sorghum (mil. Mcal)	41,364	56,952	36,378	38	-12
Sweet sorghum of arable land crops (%)	2.10	2.90	1.85	38	-12
CP availabilities, stover and grain					
Arable land crops without sweet sorghum (mil. Mcal)	82,979	82,979	82,979		
Sweet sorghum (mil. Mcal)	1,296	1,674	813	29	-37
Sweet sorghum of arable land crops (%)	1.56	2.02	0.98	29	-37
Change in availabilities over base period arable land crops gap					
ME (%)	37	41	36	11	-3
CP (%)	-31	-29	-34	-8	10